

EINSTEIN'S RELATIVITY THEORY

BY R. LAEMMEL, PH. D.



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INTRODUCTION TO THE
THEORY OF RELATIVITY

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INTRODUCTION TO THE THEORY OF RELATIVITY

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The Fundamental Conceptions of Human Thought

Space, Time and Matter

If we contemplate the reality which surrounds us or works in ourselves, we perceive an interminable flowing of everything. There is no eternal mere being, only an endless originating and perishing. "Everything flows", was already said by the ancients. But in this flow of coming into existence and ceasing to be we recognise two distinct kinds of happenings:

1. The working of nature's forces in the realm of inanimate objects. Thus the motion of the stars, the phenomena of light and gravitation, of heat and electricity; the falling stone and the oscillating magnetic needle (never at rest!); the rusting piece of iron and a solar eclipse, the fall of shooting stars or a raging hurricane: all this appears to us as the manifestation of an inanimate world.

2. The working of the vital force in the realm of organic life. Living and dying, growing and multiplying; development and decline; inheritance and mutation; these are the manifestations of a peculiar cause: life.

The forces which act in the inanimate world appear to prevail throughout the whole of the universe in which we live. Every object possesses weight, inertia; is subject to the effects of varying temperature and so on. But the converse does not hold good: the laws of life do not seem to be binding for the occurrences in the inanimate (inorganic) world. We can, of course, interpret the blazing up of a new star as the beginning, the birth, of a new world; we look upon the eternal emission of heat as a slow living and declining, on the dissolution of a starry system into dark masses of cosmic nebulous matter as a possible dying. But this is after all only a figure of speech. The natural happening — at least all that happens on earth — is due to the interaction of two powerful currents, the inorganic and the organic forces.

These two currents act incessantly on each other without ever — as far as we can see — flowing together into one. Spontaneous generation has never been observed. The living organisms form an endless chain of ancestors which at no point is linked to the body of inanimate matter.

We have here a great contrast in nature — whether real or only apparent — namely: matter and life. Matter appears to us as the more simple, life as the more complicated element. But, confining ourselves to the inanimate world only, we are here also faced by a similar contrast: that of matter and force — which naturally presents a similar difficulty. And here force is evidently the more difficult element, really as incomprehensible as life itself. That the earth “attracts” a stone must appear as a mysterious process to every thinking man. Does something go out of the body of the earth to take hold of the stone so that it is compelled to move towards the earth? For, when all is said and done, we can only understand the actual laying hold of and gripping as a force. The acting at a distance is something inexplicable — even mysterious — to us. Indeed, I do not hesitate to say: the so-called transference of thought is not more mysterious than the manifestation of gravity. Let us consider. According to the general view the sun acts on us through a distance of 93 000 000 miles. The attraction towards the sun forces the earth to revolve around it once in a year. How on earth are we to picture to ourselves this attraction through such a stupendous stretch of empty space? The answer can only be: We do not picture it to ourselves at all, we only believe it.

The contrast between matter and life has led to the development of two vast branches of knowledge: physics (including chemistry etc.) devoted to matter, and biology for the investigation of life. The further contrast of force and matter, however, is left to physics alone to settle. Even to day this problem has not yet been properly recognised, much less solved. Matter and force still move about in our thoughts in a somewhat confused manner. This is due to the peculiar character of our thinking — or brain-power, which, like everything which really exists, has its distinct limitations. Every moment we are pulled up by barriers and bounds. What goes on in our brain can only be the reflection of outside impressions, which through generations, even through earth-ages, have been acting on the human race. And only through a brain thus slowly formed can we understand the

world. Man owes the origin of the sciences to the last few thousand years; in physics in particular the last three hundred years have brought about a speedier and more important development than the preceding thousand years. More and more the conviction gained ground that the fundamental concepts of physics were identical with the most important general lines of human thought. Splendid also was the success of physics in its application to technics which gave a special character to the last century: "the century of steam", and which is going to impress another special stamp on the present one, the "century of electricity". In the proud edifice of physical teaching, mechanics holds unchallenged the first place. Aristotle defines it as the science of motions, and we have not been able to improve on this definition. The difficulty would, however, begin as soon as we were attempting to explain the meaning of motion.

Nevertheless, never was there a science able to show such triumphs as mechanics. Let us only think of the exact computation of eclipses or the movement of the stars! And, to choose a thoroughly modern example, let us think of the magnificent feats of computing mechanics in revealing the secrets in the structure of atoms! It is here where real discoveries were made. Unknown planetary systems of peculiar character were found to exist, new worlds were opened out to human contemplation by the art of computing investigation. Towards the turn of 1900 the science of mechanics was looked upon by the workers in physics as finished and complete; it was generally agreed that nothing fundamentally new could further be added to it. When I laid a small treatise on the foundations of mechanics before my eminent teacher at the Zurich university, the late Heinrich Burkhard, in 1904, he shook his head and said: the branch of mechanics is the most thankless in physics, for nothing new remains to be discovered in it!

The splendid practical and theoretical successes of mechanics led to the general belief that it could not be approached by any other science for excellence, clearness and security of its basic formulas. All the thoughts employed were cast in sharp moulds, all conceptions strictly defined and in no way employed now in this, now in another sense. In zoölogy, for instance, the expression "acquired character" may with one signify something quite different from the meaning assigned to it by another. But in mechanics a word like "velocity" can never

express anything else but the ratio of the distance described by a body to the time employed. In all sciences "to define" means the reduction of a certain conception (idea) to other simpler ones, since it would obviously be devoid of sense to try to explain a simple idea by a more complicated one. On the other hand, it must follow that we cannot but finally arrive at certain conceptions which do not admit of further reduction; which must, therefore, be looked upon as axiomatic. Just as a building if we examine its masonry from top to bottom, finally shows its foundations, the science of mechanics erected the system of its conceptions on the three irreducible, fundamental ones of space, time and matter. These were looked upon as axiomatic, as being clear and intelligible to man without any further reasoning, as manifestations of actual reality. Nevertheless, philosophical investigations have pointed out the difficulties inherent in these concepts ever since philosophical thinking and theorising began.

At the commencement of more modern physics stand Newton, Galileo and Kepler; at the end of a period of three hundred years stands Mach, the great Austrian thinker. It must be said, however, that the drift of thought of any period is never confined to one single head, nor even to three. On the contrary, the century from Kepler to Galileo and further to Newton produced a surprisingly large number of very eminent thinkers, chiefly English. Mach also, the critic of this period of classical physics, is not a solitary exceptional man but only the perfect type of the skeptic tendency which arose at the "fin de siècle" recently passed. All sciences have to experience ups and downs again and again in their development; the enthusiastic period at the beginning of an epoch, the restless work in the course of building up and elaboration, and then the commencement of a time of doubt and criticism. And while this pessimistic era cleans and tidies up the whole structure of theory and deductions, it prepares the representatives of that special science at the same time for a new epoch.

We have seen how the science of mechanics, after having found its critic in Mach, found its regenerator in Einstein. Mach represents the end of the classical period of mechanics, Einstein stands at the beginning of a new epoch which might be called the relativistic one. It also will some day have to give way to another.

The object of this booklet is to state clearly the thoughts which led from Mach to Einstein. And here we must say at the

outset, that the transition from classical to relativistic mechanics does not by any means signify a supersession of the results of physical work hitherto obtained. No; relativistic mechanics means nothing more than the extension of the classical; it is only an unavoidable further development of thoughts which were already conceived by the founder of the modern science, by Isaac Newton. And we must distinctly understand, that the further developments suggested by Einstein are only one possible way; and, moreover, have not yet been proved to be the only possible one.

The Three Assumptions of Physics

As the painter works with palette and brush, or the workman with his tools, thus the natural philosopher works with the notions of space, time and matter; but of these ideas he builds his world; with their aid he describes the coming into and dropping out of existence. But are these conceptions real things like the tools? Is there in reality such a thing as space, or time, or matter? — In spite of occasional remarks of metaphysicians, classical physics assumes the reality of these three ideas without doubt, though nobody would be able to give a simple and satisfying answer to the question: what is space? For, to what simpler question should we reduce it? Geometry also assumes space as something existing, something axiomatic. It ascribes to it three dimensions: length, breadth and depth, while a surface (plain) possesses two dimensions (length and breadth) and a line one (length) only. Geometry as well as physics conceive space as infinite in every direction; it is the vessel in which all happening takes place — after all only a very poor explanation; indeed, less than that, a mere statement.

According to the physicist of the classical period there exists in this space a time, a silent invariable passing by, an everlasting uniform moving on of the age of space. The two do not appear similarly constituted. While space can be thought "possible" by itself, time seems to be unthinkable without space.

Matter, the third axiomatic conception, is situated in space and time. It is that which is directly perceived by our senses, it is the object — the substratum — to which things happen, in which qualities inhere, the home and source of forces which act through space and time. Inanimate substance also shows in-

cessant changes. The most important is its motion in and through time. Newton already saw clearly that all matter in our world is necessarily moving. All stars and systems of stars move, all parts and particles of bodies, however large or small these bodies may be, are continually moving, they "flow".

Yet another change manifests itself in bodies which appears to us akin to life: matter changes its structure. In the sun matter exists in the form of elements, which in colder bodies (like the earth) have entered into combinations. It would also seem as if heavier elements could arise out of lighter ones. And this whole process can again become retrogressive, this complicated world-structure can fall asunder, can dissolve. This is the life of matter in space and time. Matter is for us unthinkable without space and time. And yet, natural philosophy of the classical period apprehends these three conceptions as independent of each other, and it does so simply for the reason that apparently nothing definite can be adduced to prove a connection between them.

Yet there is one case in which classical physics shows a striking connection between space, time and matter. We allude to the famous third law of Johannes Kepler:

"The squares of the times of revolution (round the sun) of the planets are to each other as the cubes (the third powers) of their mean distances from the sun."

Based on long, weary observations and endless calculations the great astronomer found this fundamental law which forms, as it were, the key to our understanding of the universe. Let us take earth and Mars as an instance. The former revolves round the sun in one year or about 31 millions of seconds. Mars takes not quite two years or 59 million seconds, so that we have $59:31 = 1.88$. Since the square of 1.88 or 1.88×1.88 equals 3.53, this figure 3.53 represents "the square of the proportion of the times of revolution of the two planets to each other". Now the mean (or average) distance of the earth from the sun amounts to 93 000 000 miles, that of Mars to almost 142 000 000 miles. The proportion of these two figures is, therefore, $142:93 = 1.524$ and its cube $1.524 \times 1.524 \times 1.524$ again equals 3.53.

Kepler, when he had discovered and verified this fact as a general law — more than 300 years ago — felt, in the first ecstasy of the discoverer as if he had unveiled one of the secrets of nature. And yet his successors have frequently smiled at him who could find such delight in a mere arithmetical relation. Indeed, this

strange law has always been underrated. The physicists, influenced by their rather colourless conception of the world regarded the formal connection of the things of this world — as expressed by a mathematical formula — as something useful chiefly to supply problems for teaching purposes. Nobody imagined that the relation of the squares of time to space indicated a natural connection between the fundamental conceptions of time and space themselves.

Now it might be rightly objected that every natural law creates a connection between the ideas employed. We all have learned at school the following laws of the free fall of a body.

1. All bodies fall with equal velocity; iron falls with the same speed as copper, one pound as quickly as two or three. Whatever the substance may be and whatever its weight, the velocity of the free fall increases by about 10 meters every second.

2. The ways described by a falling body are to each other as the squares of the times required. During the first second the way is about 5 meters; at the end of the first two seconds it is not twice but four times as long, after three seconds nine times and so on.

These laws were discovered by Galileo, a contemporary of Kepler. They seem to express another connection between time and space. Which (we may ask) is the true connection? Well, what we call the free fall is a phenomenon taking place on the surface of the earth only, a motion of a few meters in extent. When a body falls onto the earth from a great distance, quite a different law is revealed. For during the fall the force of gravity increases, or in other words, the increase of velocity does not remain uniform, it grows. If the moon were commencing to fall towards the earth, this increase would amount to no more than $\frac{1}{4}$ centimeter per second. As it approached the earth, this increase of its velocity would continue to grow until it would reach finally the value of 10 meters for every second. Further calculation shows that this fact can be expressed by the following law:

3. The squares of the times consumed by bodies falling from a great distance are to each other as the cubes of their distances from the earth. (This law was advanced by the author.)

It was, therefore, not Galileo who discovered the general law, but Kepler. Thus we arrive at the clear and certain knowledge that for every kind of motion (as p. e. that of falling) a connection exists between space and time which has its foundation in nature itself. It is easy to see that the mean time of

revolution of a planet round the sun or the time of rotation round its axis would form the "natural" unit of time for each special planet. While an inhabitant of Mars would consider the terrestrial year rather a short one, the dweller on the earth finds that it is just a year. Carrying our thoughts further in the same direction, for instance as to the possible duration of life of beings on Mars or on Jupiter, we recognise that for every kind of motion (i. e. for each planet) a different measure of time might well be possible, even natural. And further: if the Jupiter-year should mean to the Jupiter-inhabitant the same as the terrestrial year means to us, the Jupiter-astronomers would marvel at the extraordinary speed at which our daily life passes by. Conversely, we should think exactly the opposite of the life of the "Jovians", as their one year represents in duration 12 terrestrial years.

Similarly as to the units of space. Suppose the Jovians had based their unit of length like us on the dimensions of their planet, the Jupiter-meter would measure as much as 12 earth-meters. (Is it accidental that the figure 12 occurs here again? Who knows; for: is there such a thing as accident?) In any case, the ancient thought: "all is relative, nothing absolute exists" can be applied also to space and time. In biology the duration of life of an organism might also be chosen as a natural individual time-unit, so that an ephemera might see in the short space of its life the same fulness of time as another long-lived being in its own: infancy, youth, full vigour, age and death!

Thus without difficulty we are led to introduce individual measures or, more exactly, units, for every kind of motion. The thought is not new. "Everybody must be measured by his own measure", "the measure of all things is man" are ancient maxims or precepts, hitherto mostly applied from a moral point of view. Now, however, we need them for the further development of the classical perceptions of mechanics. They strengthen our tolerance of thought; they give us courage to doubt everything in order to build out of these doubts the best possible view of the world.

Reality in Terms of Motion

The ideology of mechanics seems to be a masterpiece of the art of human thought. The general meaning of each notion employed is at first laid down; then a suitable unit is agreed

upon. The fundamental conceptions, space, time and matter — though themselves not further definable — have their fixed units. They are (in physics) the centimeter, the second, the gram. Now the mechanical interpretation of reality aims at reducing all happening to motion. It would not be easy to explain exactly what this means. "When a body changes its situation in space in the course of time . . ." — but here the expression "change" involves already the idea of "motion", which is just what we want to explain. For after all, "changing" is nothing but "moving". From the viewpoint of mechanics every change is a motion, from that of philosophy every motion means a change. Though we may call space, time and matter axiomatic conceptions of physics, we can not thus define all that science needs in its further development. The word "motion" does not express a sharply defined physical abstraction. In the first place, motion is characterised by its velocity or by the distance described divided by the time employed, no matter whether the motion is a mean (or average) one, whether it is momentary or local. The average motion of the earth, for instance, in its yearly revolution around the sun, is obtained by computing out of the mean solar distance of 93 000 000 miles the length of the earth's orbit — 584 000 000 miles — and dividing the latter by one year or 31 500 000 seconds. The resulting mean velocity amounts to $18\frac{3}{4}$ miles per second, a value which we shall have to make repeated use of.

As a second instance the velocity of a train at the very moment of its passing could be found in this manner: We place two electric contacts at a moderate distance from each other on the rails, the first of which is so constructed so as to release, the second so as to stop a clock movement. Then the clock will indicate the time during which the train travelled from contact to contact. The division of this distance by the time gives us the velocity of the train. The nearer together we place the contacts, the nearer shall we approach to the velocity at the moment of passing, in this case evidently also the "local" velocity for that particular spot.

A gradual change of any motion leads to another conception: acceleration. This expresses the proportion of the observed change to the time of its completion. In the case of a falling body, for instance, the velocity changes every second by 9.81 meters. This amount is, therefore, the acceleration of a free fall. It is necessarily

not quite the same at different places on the earth; and if one were to rise very far above the earth's surface, one would also observe a change — a decrease — of the acceleration. This decrease obeys everywhere the general (Newtonian) "quadratic" law. The acceleration of the moon's motion towards the earth, for instance, would be 3600 times smaller than the above value 9.81, since the moon is 60 times further removed from the earth's centre than we are.

An acceleration of any mass or body must have a cause; such a cause is called a force in mechanics. Every accelerated motion must, therefore, owe its existence to the action of a force. If the acceleration is negative, it becomes a retardation which readily reduces the velocity. Since Galileo's time the following important thought was arrived at: if the motion of a body takes place without either increase or decrease of its velocity, so that it remains absolutely unchanged in magnitude as well as in direction, there is no force acting on the body but only its inherent inertia. Or "Force is the cause of change of motion, inertia that of its remaining unchanged". But this explanation does not carry us much further, since — to repeat it once more — the essence of the acting of a force is in reality an unsolved riddle. Still the idea "force" has answered very well for mathematical treatment. It is measured by the product of the moving mass and the acceleration of its motion. If no acceleration is observed, no force is influencing the body, but it obeys only its inertia, which may mean either rest or uniform motion.

Now again: rest and uniform motion are just such products of the imagination as, say, a "straight line" or a "circle". Within the reality accessible to our observation there exist neither straight lines nor circles, neither uniform motion nor absolute rest. A knife lies before me on the table; is it at rest? How could it be since it is carried along by the earth in its motion.

From the viewpoint of classical mechanics every real occurrence must presuppose a change of something. These changes, on close examination, prove to be really nothing but the changes of the mutual distance of two bodies. This distance is, roughly speaking, the nucleus of all that happens on earth or in the world as far as it can be mechanically understood. All the mutual distances of all existing bodies are everlastingly changing. How inadequate or even paltry does the mechanical perception of the universe appear if thus laid bare! And yet, what stupendous difficulties are hidden in all these apparently simple remarks!

We proceed. Changes, wherever they occur, are called "work" performed or mechanical effect. If I remove a body further from the earth by lifting it up, I perform certain work or produce a certain mechanical effect. If I tighten a spring by forcibly altering the natural arrangement of its substance, I am again performing some work. And here it is important to observe that all occurrences in the universe are in truth nothing but an endless chain of successive changes. And these changes are connected with each other both as to space and time, a connection we denote as "cause and effect". For instance. I wind a clock. The change produced (the work performed) lies in the tightened spring. It makes the clock go. The motion of the wheels and pendulum (which also requires a constant impetus) changes into a hardly perceptible heating of the clockwork and the surrounding air. Thus all happening appears as a series of changes which alone are real and observable. And between all these successive changes there is no room left for "forces". We can only say that these successive changes involve each other, no more.

When a moving body collides with one at rest it performs some work; a moving stone may cause the mechanical effect of a broken pane. This work which can be performed by a body in motion is called "its kinetic energy" (living force). A body can continue to perform work until its velocity equals zero. The mathematical formula for the kinetic energy of a body is half its mass multiplied by the square of its velocity ($\frac{1}{2} m \times v^2$). And it became gradually recognised in physics that in truth all work performed or even all capability of performing work must be the result of some motion, that all energy must be kinetic. This recognition proved particularly important in the theory of heat, which to-day is based on the fundamental assumption that heat consists in the movement of molecules (the smallest quantities of substance capable of existing in separate form). Robert Mayer, a physician by profession, discovered this law: energy cannot be created out of nothing, neither can it, once it exists in any form whatever, disappear into nothing. Half of this law has its analogon in life, which, though it can be destroyed, can never be created.

Let us elucidate an essential trait in the world-picture of classical mechanics by this simile. Matter is the carrier of cosmic happening. Space and time are the vessel in which the happening takes place. The vessel may be conceived without its contents, but the contents cannot exist without the receptacle.

The Units

A meter, the unit of length, is the 40 millionth part of the meridian of the earth. This is, of course, not exactly the case; the standard meter, preserved in Paris, is in reality slightly shorter. It is subdivided into 100 centimeters and 1000 millimeters. The English equivalents are 1 meter = 3 feet 3.4 inches; 1 centimeter = 0.3937 inches.

The second is the terrestrial unit of time. It is the 86 400th part ($24 \times 60 \times 60$) of a solar day. Since, however, the days are not all of equal length, we must divide the mean or average length of a solar day, as it is obtained in the course of a year, by 86 400 in order to derive a second.

The unit of mass is the kilogram. It is the quantity of water (or any other substance of equal specific gravity) contained in a liter or 1000 cubic centimeters. The English equivalents are 1 cubic centimeter = 0.0610 cubic inches. 1 Liter = 1.761 pints.

The unit of force is the weight of a kilogram or the force with which the earth attracts a liter in the middle of Europe. We have 1 kilogram = 2.205 lbs.

The kilogram-meter (kgm) is the unit of work or energy. This unit of work is performed by lifting a kilogram one meter high. It is, by the bye, a fairly small quantity. A day's work of a man, performed as unskilled labour, amounts to about 100 000 kgm.

A horse-power is the unit of the performance or "effect". It is done if the work amounts to 75 kgm per second. The continued work of a real horse is only about 30 kgm per second, that of a man — reckoning a working day of 8 hours — is about 8 kgm per second.

Absolute and Relative Things in Our World

An air-ship may fly across the country. It will be every moment at a fixed place which can be definitely laid down by means of exact data. The height of the ship above the earth in particular is such a datum. But as every point on the surface of the earth is itself already determined by two data, its latitude and longitude, three data are certainly required for the location of an air-ship at a given moment, viz. longitude, latitude and height. This appears to us as something quite natural, since space extends in three directions (possesses three dimensions).

These three coordinates, which determine the place for any moment, change, of course, continually in the case of a moving object. And as the state of being in motion is a natural and general one, we might define the task of mechanics as that of ascertaining the changes of positions of all bodies in the universe. This is the ultimate object of natural philosophy. One difficulty, characteristic of our world, presents itself at once: it is impossible to fix the place of a point absolutely; it can only be done relatively to some body, or other point. In the above instance the place of the air-ship can only be obtained with reference to the earth or to some special point on its surface, since the earth rotates around its axis and revolves around the sun. One might, of course, say: as the absolute position does not concern me it fails to interest me. But this does not remove the difficulty out of my mind. For the value of the velocity and the path described also depend on the point to which we refer the data. A numerical example will make this clear. Suppose the speed of the air-ship to be 50 m a second and that it moves directly westward. We — tacitly assuming the earth to be at rest — shall say that it moves in a straight line to the west with a velocity of 50 m-s (meter-seconds) relatively to ourselves. But an inhabitant of the moon, watching the air-ship, could not fail to notice the rotation of the earth. To him the surface of the earth appears entirely different from the face of the moon to us. While the moon always turns the same half of its surface to us, the observer on the moon sees one continent, one ocean after another, pass his vision. Our air-ship would, in consequence, appear in this way. It has in our latitude a velocity of about

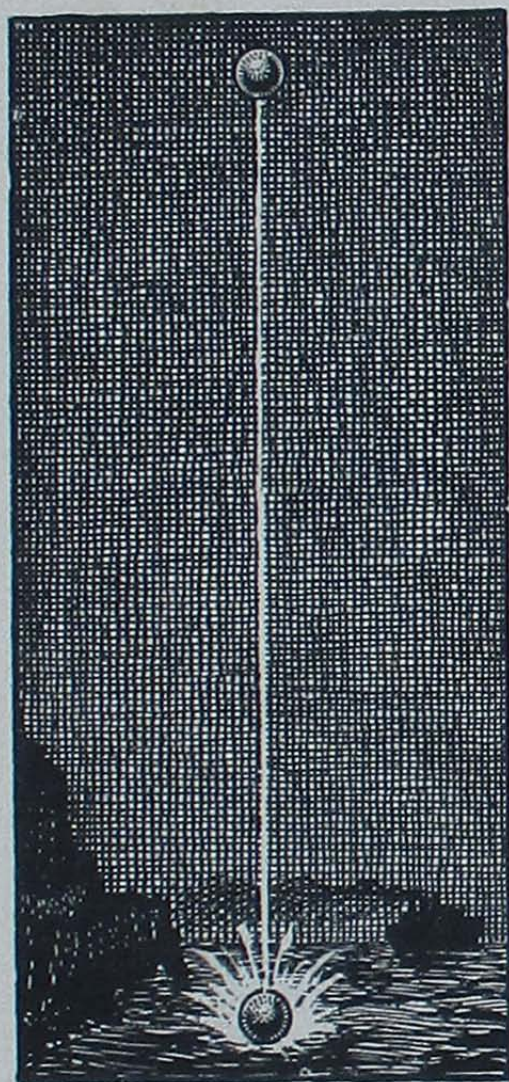


Fig. 1. A ball falls vertically onto the earth from a height of 500 m (1640 ft).

300 m-sec. around the earth's axis and at the same time the velocity of 50 m-sec. As it sails towards the west, its resulting speed will be 250 m-sec, and the lunar observer will conclude: the air-ship revolves round the earth with a velocity of 250 m-sec. towards the east and it describes a circular path.

Now let us assume that the same air-ship could be observed from the sun. Seen from there its chief motion must be its participation in the revolution of the earth around the sun. And as only a very small portion of the earth's orbit can here be concerned, the solar observer will say that the air-ship moves onward in an almost rectilinear orbit with a velocity of 30 kilometers per sec (km-sec). And only very accurate further observation will reveal slight irregularities in this motion which are caused by the air-ship taking part in the rotation of the earth and by its possessing a motion of its own relatively to it.

Here we have tacitly assumed the sun to be at rest, which is in no way the case. Firstly it rotates around its axis, as proved by the movement of sun spots; secondly, it moves in space (in a manner not yet completely known) in the direction of the constellation Hercules, and all planets, tied to the sun by the link of gravitation, are forced to accompany it on this journey through space.

Thus it becomes evident that the real motion of our air ship in space cannot be described. We are only able to make some statement about its motion relatively to something else, whatever it may be.

Similar reflections can be made with regard to the path described by a falling body. Relatively to the earth it is a straight line, directed to the centre of the earth. To the lunar observer the daily rotation, which the air-ship takes part in in consequence of its inertia, becomes apparent, so much so that its own falling motion can only be recognised with difficulty. And to the solar observer the yearly revolution of the earth around the sun will be by far the most conspicuous movement of the falling body. And further: the falling stone reaches together with the whole solar system into unknown depths of universal space. What then is its real motion? Perhaps, observed from any particular star, it is seen to screw itself into the cosmos. Who could find out the real nature of this motion? And from every other star a different motion of our falling body would be observed (in detail though probably not in general character). We know that all fixed stars, so-called, are moving relatively to each other. And suppose

that one among them could be considered at rest, yet as every thing else is in motion, we could never observe or prove the fact.

We are thus like sailors on the high seas without fixed bearings. The space which surrounds us contains scanty masses of stars



Fig. 2. The same ball, observed from the moon, is seen to describe an arc, 3042 m in length, as it rotates around the axis of the earth during its fall. (Scale of drawing much exaggerated.)

between which extend tremendous empty voids. And through these vastnesses the stars move, whether quickly or slowly we know not. Imagine a swarm of midgets dancing in the sun; the mutual distances of any two midgets are forever changing while the whole swarm, as such, also possesses a progressing motion. Think of a flight of starlings; thousands of birds cross the air in

a body and are besides in constant motion relatively to each other. Can our stellar system be compared with such a flight of starlings? Or, in other words, is there such a thing as a prevailing direction in the movement of the fixed stars — a drift of stars — through space? We do not know. One might even think it possible that we never shall know. Universal space extends without boundary or barrier in all directions; it presents the view of an incessant flowing of all its parts. What shall we consider as real in all this chaos? What is to be taken as absolute? Where is our earth and whither does it really travel?

These two questions, where? and whither? present both their difficulties, each in its own peculiar degree. For the first — where? — seems to be quite impossible of ever being answered.

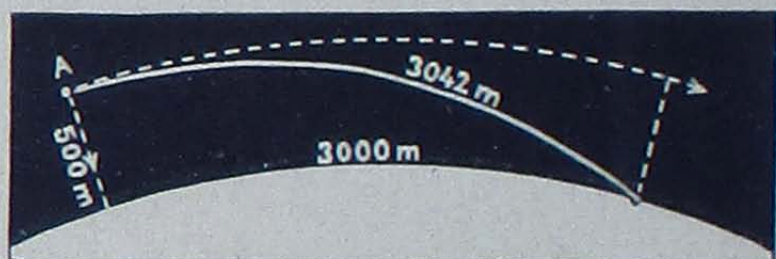


Fig. 3. Schematic section, or side-view, of Fig. 2.

How should an orientation be possible in endless space where all stars are in incessant motion? The second question — whither? — seems to be almost equally hopeless. If there existed in space a prevailing direction, a drift of stars, we could refer our motion to this drift. We could either take part in it, or we could be swimming against the stream of worlds, either directly or at an angle. But the existence of such a drift has not yet been established beyond doubt. If all stars, without exception, carried out a definite motion in space, they all would travel with equal velocity parallel to each other. And this motion we could never perceive on account of the special nature of our organism which permits us only to perceive relative displacements. But we could never recognise a motion of the whole stellar system as long as its internal arrangement (the position of its parts relatively to each other) remains the same.

If we, however, imagine the world-space to be filled with ether, a substance of extreme thinness which permeates matter as well as the voids of space, the question, whither? appears soluble. Ether might be defined as the finest (thinnest) primal

form of matter. It is — perhaps — the ultimate source of matter; every stellar system arises out of it and dissolves again into it. It must be imagined still finer than the nebulae in the universe. While these are at times so thin that stars can be seen through them, ether is in a state of such inconceivably fine distribution that all stars without exception can be seen in and through it. But it must consist of separate particles, or it would lack the characteristic of real matter. If such an ether does exist and if it does fill all space, motion might be determined “absolutely”, so to speak, by referring it to this all pervading substance. The

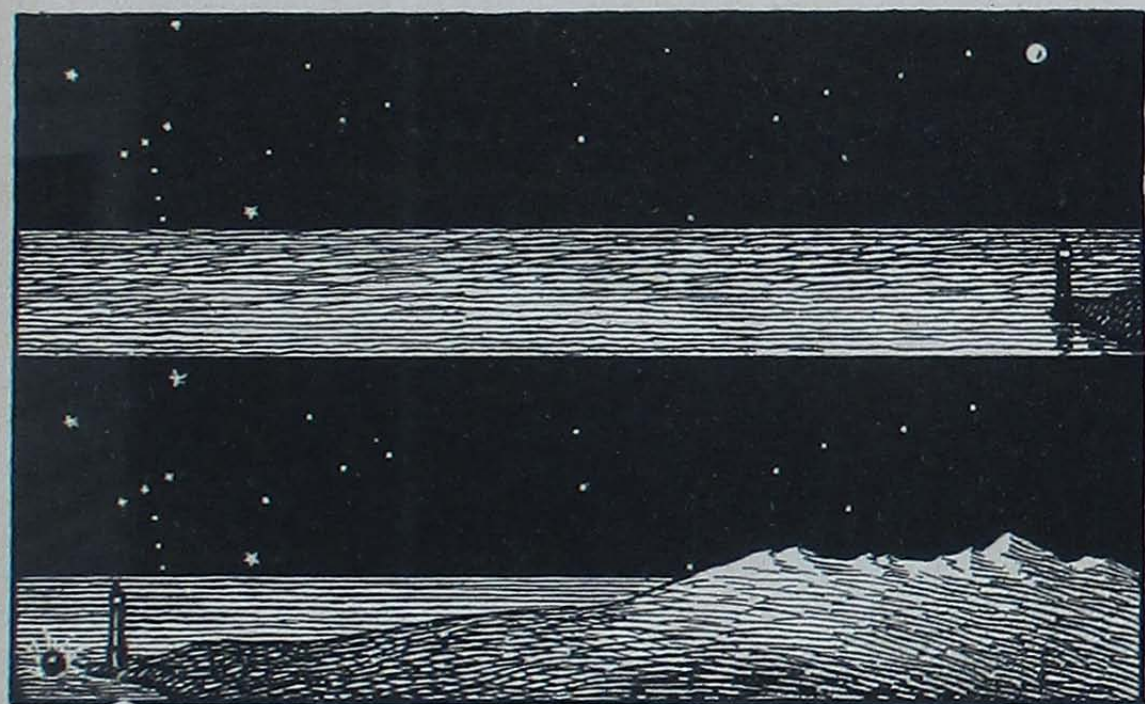


Fig. 4. An observer standing free in space and looking towards the south will witness the fall of the ball somewhat as here represented. Special attention to be paid to the unmoved starry sky

question “where?”, however, could not be answered with “absolute” certainty, since the space of classical mechanics is assumed to be infinite; but the direction of a motion might be regarded as real if it could be fixed relatively to this ether.

But what of the new complication which must arise if ether itself were also in motion? It might move as a whole, or in streams or drifts through the cosmos, i. e. it might form streaks in space and perhaps act on matter. Or again: it might be at rest. A motionless ether would suit us best of all, for then we should have something really solid and fixed to enable us to recognise real motion. A necessary consequence of a “resting” ether would be,

that we on our wanderings through space would have to face a gale, so much the more violent the quicker our progress through the resisting ether; just as we feel a violent draft when we ride in a motor, not a real wind but only a motion of the air relatively to us. Now such a thing, such an ether-gale has, we need hardly say, never been observed. Though this fact would not be very serious from the view-point of mechanics, it becomes more critical from that of optics. For it was just for the purpose of having a carrier for the radiation of light and electricity that the ether was invented. Even the passing of light through glass

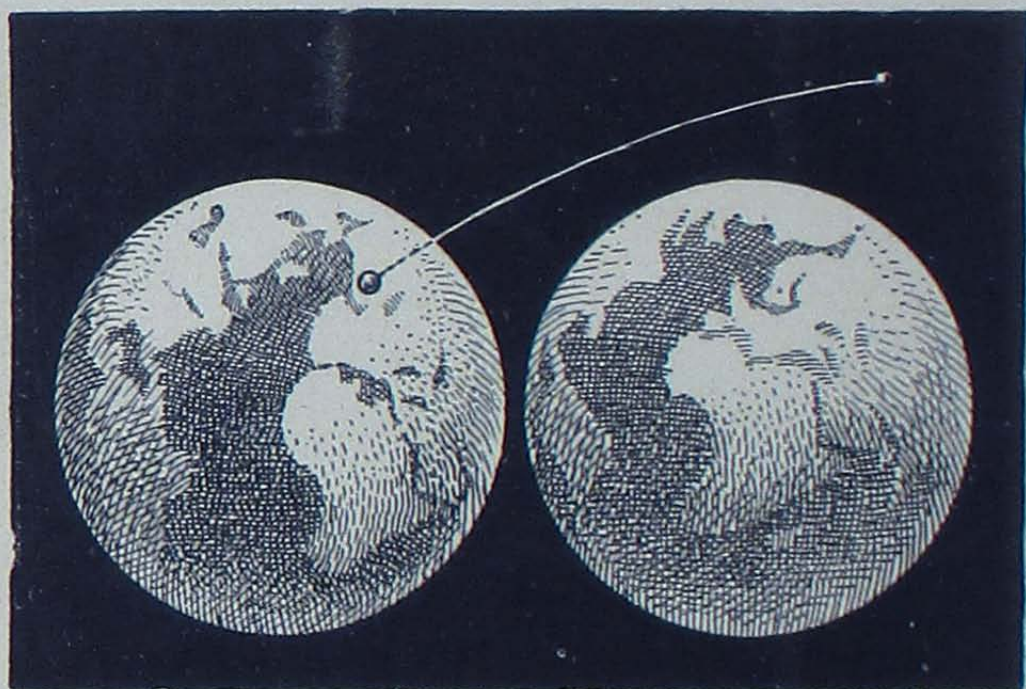


Fig. 5. The observer on the sun sees above all the forward movement of the earth in its orbit. Scale exaggerated.

or water is only possible owing to the existence of an all pervading ether. For the oscillations of ether produce "light".

Though some observations agree with the existence of a motionless ether, others are incompatible with it. And yet, though this has never been explicitly stated, the assumption of an ether which is absolutely at rest is an indispensable preliminary condition for the building up of the classical system of conceptions. For without it the fundamental idea of inertia becomes unthinkable. This idea, introduced by Galileo, postulates that a body, left to itself free from any external forces and only under the influence of its own inherent qualities, must move on in all eternity at a

uniform speed in a straight line. Real experience, however, teaches that such inertia can only exist for a very short time; that no motion which we can follow for some time remains either uniform or rectilinear quite apart from the effect of friction. For we can never get rid of the force of gravitation, wherever we may be in space, so that the most important condition in Galileo's definition of inertia is, in practice, not fulfilled. No body which moves in our world can emancipate itself from the constraint or spell of gravitation towards other bodies. Every real motion will be disturbed by gravitation just as much as we observe it

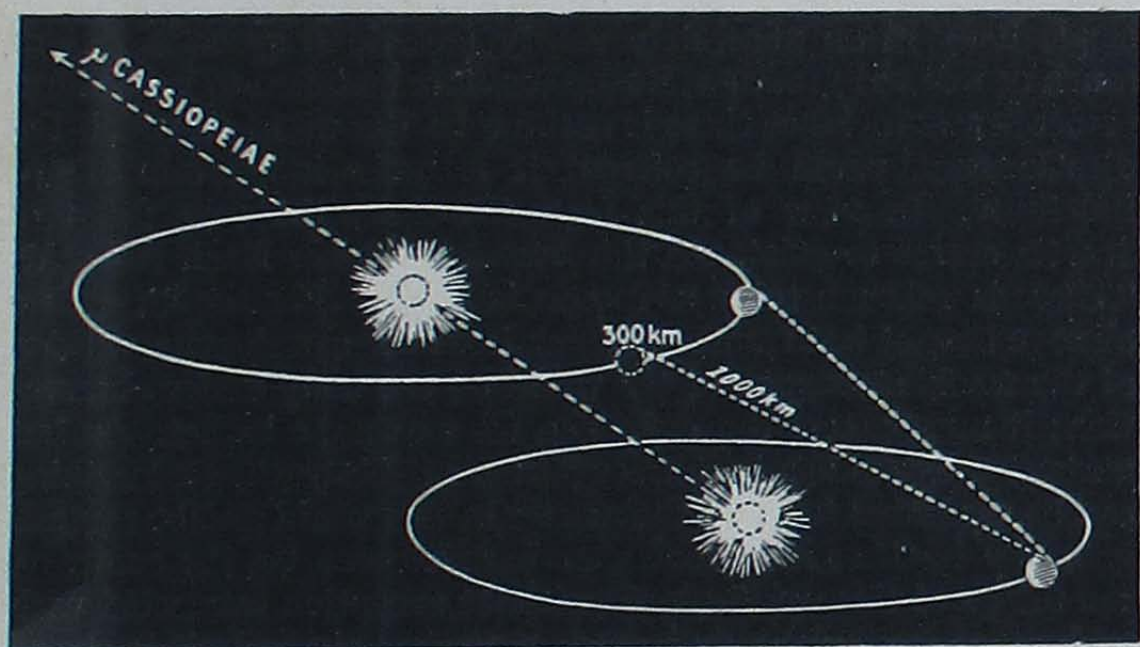


Fig. 6. Our sun with its planets moves at the rate of about 1000 km (620 miles) every 10 seconds away from the star μ in cassiopeiae, which lies at a great distance, below to the left.

daily on the surface of our earth. If we throw a stone in any direction, it "shows not the slightest inclination" to move in a rectilinear path. It "obeys" the law of gravitation and moves in an orbit of "compromise" which, on the earth, would be a parabola (approximately). And it must not be forgotten that the moon and sun also exert their influence on the stone. When we called the resultant curve a path of "compromise" we meant a sort of mutual agreement between the influence of inertia and the effect of the earth's attraction. In order to escape this influence of disturbing forces of gravitation it has been said: a body, pushed out into empty space, free from all attracting masses, will move on in an ideally straight line at uniform speed. But

this conception tacitly presupposes a "resting", a motionless ether! For if there are to be no masses in space, there will either be no orientation possible or only in relation to the motionless ether. Ludwig Lange arrived at this same conclusion early in the seventy's of last century. He assumed space to be filled with ether and placed in it straight lines as flying tracks of thrown bodies.

If our universe is filled with a motionless ether, this ether must be the only absolute thing in the world to which we can refer the law of inertia. Thus natural philosophy (mechanics in particular) is forced to assume the existence of ether. For a single body in an absolutely empty (etherless) space is just as much at rest as in motion; its motion may be taken to be uniform or accelerated. Since there is nothing in the world to which the displacement could be referred it is quite indeterminable or indefinite. In view of this fact, therefore, the conception of inertia ceases to exist. As the Austrian thinker Mach has said: "There is no such thing as inertia in itself." For the inertia we observe cannot but result somehow from the simultaneous action of the whole star-mass of the world on the body under observation; it must mean the existence of cosmic bodies. An important progress lies in the recognition of this truth, that nothing can be separated from all the matter in our world and be investigated by itself as if it alone were in existence. On the contrary, the things of this world are all without exception connected with each other and exist only in their entirety. Similarly it is one of the most important points of Einstein's doctrine of relativity (we anticipate here in continuance of our preceding line of thought), that space and time cannot exist separately from each other, but that only the continuum of space, time and matter forms a reality.

Now let it be plainly understood, that neither the existence of ether, nor its state of rest, can be proved. Consequently, if we assume this hypothesis that ether is the one thing in the world which is absolutely at rest, we cannot turn this assumption to any practical use, since neither with our senses nor with any instruments can we prove the ether's existence. Thus after careful thought we arrive at this first proposition:

- I. The position of a point can only be indicated relatively to arbitrarily chosen bodies of reference. The direction and magnitude of a motion can also only be stated relatively.

Bearing the second half of this statement in mind, we must emphasize the fact, that we are in every way unable to say how our earth really moves in space. Relatively to the sun its velocity amounts to 30 kilometer-seconds; relatively to the fixed stars it is generally adopted that sun and planets possess a velocity of about 20 km-sec. towards the constellation Hercules.

This is, however, by no means proved beyond any doubt, being based upon the following hypothesis about the "real" motion of the stars. The stars move in all possible directions like the molecules, so that there are no drifts among them and that the mean displacement must equal zero. In other words: as many stars move forward as are moving backward. Now it has been observed that the stars in the neighborhood of the constellation Hercules appear to move slowly apart in the course of centuries, while in the opposite part of the sky (invisible to Europeans) there is a region where they seem as slowly to approach each other. These two movements are not supposed to be real but only the reflex of the real motion of the whole of our solar system which is directed towards the constellation Hercules.

This is certainly true as far as it goes. If we walk along a straight road planted with trees on both sides, the trees before us open out and increase their mutual distance, while those behind us close up together and reduce it. But the essential difference between stars and trees is this: the latter are at rest relatively to the earth, but who can say which stars are at rest and which in motion? Who can vouch for it that the stars are not actually increasing their mutual distances near Hercules? As we are not capable of knowing anything about this, all conclusions based upon the zero-value of the average displacement of the stars are nothing but possibilities. We do not know with absolute certainty where the solar system moves to in space, nor at what speed. This recognition is the nucleus of the classical principle of relativity. We are wandering blindly into space; uncertain alike is the beginning and the end! Newton, the great English thinker, was the first man to arrive at this knowledge. But the incontestable impossibility of ever fixing absolutely a place or position in space, appeared to him so uncanny, that he began to doubt his own logic. It is the only point in his "Principia Mathematica" where the master ceases to be sure of himself. And when his intelligence sees that an absolutely fixed point cannot be laid down by us in space, he becomes untrue to himself: he thinks the matter

might, after all, not be quite hopeless. We, however, who live to-day, cannot avoid the conviction that it is hopeless!

Are we, consequently, to assume — in the sense of traditional physical logic — that everything is relative? — By no means! Space and time are still considered as absolute! At least, Newton has pronounced this, and it is still taught at our universities. Matter also is something absolute in the sense of classical physics. These three fundamental conceptions are forms of reality in space, though we can understand the position of a point and the value of velocities in this space only relatively. Here now it becomes necessary to mention yet another conception of an absolute quantity in classical physics which was not recognised as such until the age of relativity was already dawning on the horizon.

It may be put in this way. The position of a point can only be fixed with reference to a definitely chosen system, and the data which determine the position change when we pass from one system to another. A mountain which is 548 meters high above the surrounding country, has the height of 1034 m above the level of the Mediterranean and of 1039 m, above that of the Atlantic ocean. But if we consider instead of the place of a single point the distance between two points, the aspect of things changes completely. For in classical physics this distance is a thoroughly absolute quantity. The length of a staff remains the same, whether it lies before me on the table, on the top of a mountain or on board a passing air-ship. A meter-measure falling onto our earth would appear as a meter-measure to everyone. Lengths are not relative but absolute.

The same reasoning can be applied to time. The initial point from which it is counted is arbitrary, just like the fundamental place for measuring elevations. Yet the duration of an event does not depend on the choice of an initial moment of time. The affinity of space and time is already shown in our using the same word "length" for meters as well as seconds. Most readers are familiar with a stop-watch as used for recording races. It measures short intervals of time counted from a known but arbitrarily chosen point of time, because the measured interval does not depend on the time of its commencement. If anything lasts three seconds, it is immaterial which actual local time the watch indicates. These three seconds are an absolute quantity. Thus we have this second axiomatic proposition of classical physics.

II. Distances are absolute quantities. That means, they do not depend on the system of reference chosen for their measurement. This holds good for distances of length in space as well as for distances (or intervals) of time.

Thus the world-picture of classical physics becomes clearer and more compact. We see before us a combination of absolute and relative things and conceptions. This picture possesses without doubt a high degree of perfection and usefulness. We may proudly say that the last 300 years, which cover the achievements of Galileo, Kepler, Newton, Euler and Mach, have deduced a technical world of marvels from this picture. But there is no halt for us, no fully completed development. Nothing is ever completed. The belief that mechanics had arrived at finality of perfection was an error.

We may define proposition II as the principle of absoluteness in mechanics. But it is not the only conception of the absolute in the system of classical mechanics. It is important for the development of the modern (Einstein's) theory to add the following classical principle: velocities in the same direction combine like natural numbers by simple addition. A man, therefore, who walks in a corridor train towards the engine, appears to an outside observer to be moving with a velocity exactly equal to that of the train plus his own velocity relatively to it. If the velocity of the train amounts to 20 m-sec., his own (relatively to the train) to 2 m-sec., his speed to an outside observer is 22 m-sec. This axiomatic thought of mechanics obviously means, that the two different velocities are altogether independent of each other, so that the resulting velocity, referred to a system outside the train, must equal the sum of both.

Hence the third proposition, the principle of addition:

III. If two different velocities in the same direction are imparted to a body, it will move with a velocity equal to the sum of both.

A velocity already existing could thus, by the addition of others, be increased indefinitely. This agrees in the end with the classical assumption of the infinity of space, because infinite velocities can only be imagined within an infinite space. The above third law is of special importance because it allows us to exemplify clearly the "classical" mode of thought, where the word "classical" alludes to the epoch when the science had attained

its most flourishing state of development. Such a period is — in every science — distinguished by a lively activity of creation. Wide reaches in the realm of a science are explored with fiery zeal; wonders are achieved within a short time by a small number of men. The leading spirits of such an inspired period are more or less consciously imbued with a few prevailing thoughts out of which they create their works.

What was this all pervading thought, this leading classical idea, in the development of physics? We, living in an age of transition, can naturally only guess at it, but I think that the classical period of physical development — from Galileo to Mach — was chiefly influenced by the idea that nature, in all its thousandfold manifestations, is subject to laws expressible by simple numerical (arithmetical) relations. I imagine a confined space filled with air. The air inside has, of course, a definite volume and is under a definite pressure. If we now reduce the space by one half, (without altering the temperature), the air-pressure rises to double its value. At least this was adopted for a long time as a certain self-evident law, until, at the end of the 19th century, it was discovered to be only approximately true. In fact, nature had given to gases a more complicated law to obey. Yet another example. Introduce into a certain vessel a gas which exerts on its sides a pressure of 5 kilograms to the square centimeter. Then I add another gas which, if it were alone, would exert a pressure of 2 kg to the square centimeter. One might expect that both gases together would exert a pressure of 7 kg-cm. This is indeed such a near approach to the truth that for a long time it was adopted as the exact truth.

If we carry an iron scaffolding, 2345 m in height, to the top of a house of a height of 12 587 m, we take it for granted that the uppermost point of the scaffolding will be 14 932 m above the ground. In all these instances the opinion is apparent, that in the end all physical laws may be expressed by means of simple arithmetical laws. — Or, in a few words (though not very accurately expressed): Realities may be added like numbers. If we look on realities (heights, velocities, pressures etc.) from this viewpoint, we may treat them as pure numbers which do not influence each other. Always, of course, under the supposition that these realities are independent of each other.

But in the real world all things (strictly speaking) do influence each other. So one might well expect that the erecting of the scaffolding on the top of the house might show [itself in the

height. For is it not evident (for instance) that the scaffolding must compress the house to some extent? Let nobody consider this as irrelevant. On the contrary, the matter is of fundamental importance, for the exact sum does not result. Though no doubt $3 + 4 = 7$, a body of 3 m in height placed on one of 4 m does not necessarily lead to a total height of exactly 7 meters. Thus we obtain the general truth: real things, when acting together, influence each other; they never combine simply arithmetically (in sums or differences).

In this way, still on the platform of classical physics, we obtain a hint of what the new epoch of knowledge has shown: things are insolubly connected with each other. There is nothing which might be considered as isolated, detached, — independent of the surrounding world.

This result, though it may touch the inmost numbers of the new doctrines, does not stand at the entrance of the new principles. Here stands rather the negative of proposition II, the negation of the absolute character of length and time. This negation formed naturally a surprise for our mode of thinking; how it came about must now be shown.

The Experiment of Michelson and Morley (1881)

One of the many miracles of everyday life which we are in the habit of passing heedlessly by, is the reflection of light in a looking-glass. A luminous something, about whose real nature we know nothing, floats against the reflecting surface and is thrown back like a ball flung against a wall. The light itself, however, we never perceive; we see bodies, the dust-particles in the air, the objects in the room. Light passes through an empty space without itself being seen. Therefore at night we see the space of heaven stretched over our heads like a vault. And though we do not see the solar rays in an empty space, we must yet suppose that the sunlight surges uninterruptedly right around the earth, day and night. The blue sky is nothing but the air in its true colour; behind it lies the black sky. Nothing could therefore, be more natural than to imagine beyond the air the existence of a very thin, delicate substance which fills the whole universal space, but which cannot be seen because it is too thin. For as we do want something in which the light spreads, the conception of the ether was at least of great practical value.

Let us, therefore, suppose the reflection of light to take place in the ether. A source of light may be in L (Fig 8), a mirror (vertical to the plane of the drawing) in S, so that the ray of light proceeding from L (LS) is reflected towards RS. The source of light has been shut up in a case from which only a very thin ray (a single ray, so to speak) can escape through a narrow slit. Or, — to interpret the drawing in another way — we assume that a stone has been thrown into water at L. We all know that it causes waves to form, which spread in all directions from the spot where the falling stone touched the water. Let S be a quay-

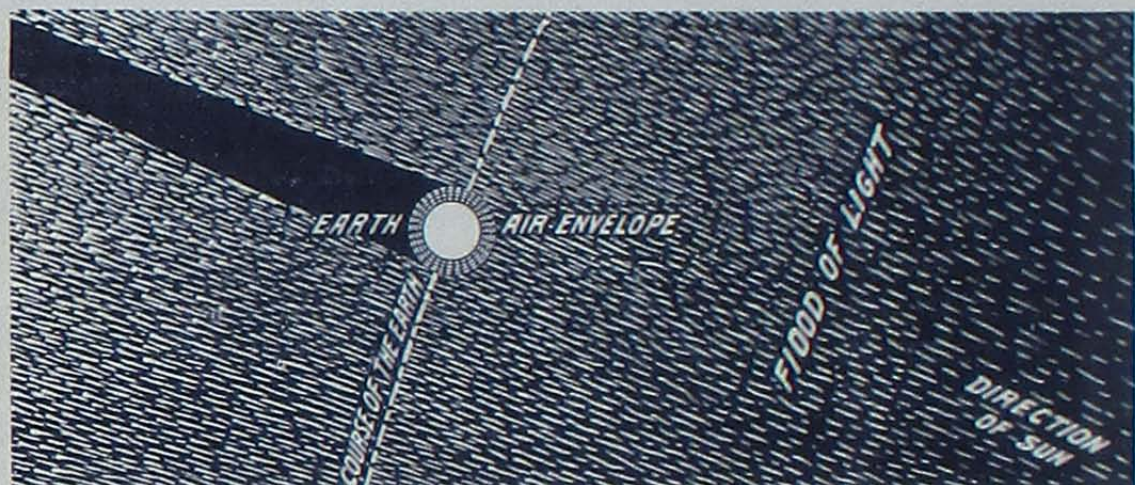


Fig. 7. The earth in the sea of light.

wall which must, of course, reflect the waves; and these reflected waves move (as is easily perceived) symmetrically to the first, "incident", ones.

Well, in both these cases — whether L be a source of light and S a mirror, or whether we prefer the cruder interpretation of a falling stone and water — all objects were considered to be at rest relatively to each other. If we now let the whole system, the source of light L together with the mirror S — move through the ether, this would obviously mean that the waves towards the quay-wall were produced from a moving boat, that the water was not stationary but flowing. For the result would be the same for both cases; it can be expressed in the one sentence: water and wall are in relative motion. This fact must evidently become somehow apparent in the aspect of the waves. For if a swimmer were proceeding from L towards S, it cannot possibly be a matter of indifference, whether the water rests (relatively to S) or not. To make it quite clear that a relative motion is

here before us, we carry out the experiment in the swimming bath of an Atlantic liner. Then the water between L and S appears at rest relatively to the swimmer, while an observer on the shore perceives the motion of the whole.

In Fig. 9 we have two boats at a fixed distance from each other in still water. A man swimming from boat A to boat B would use the same time for his return journey B to A, — (if we leave any disturbing influences, such as fatigue and so on, out of consideration). Now the two boats are to move uniformly onwards, while they retain the original distance from each other. Then it is quite clear that the swimmer from A to B can only reach boat B if he swim more quickly than the motion of the boats. It is also evident that the onward motion of the boats must have a retarding effect on that of the swimmer. He will require more time to reach B from A than before. On his return journey from B to A the motion will cause A to meet him on his way, so that he will want less time to reach A, not only in comparison to his preceding journey from A to B, but also to that between stationary boats on a lake. Now we might think, that the loss of time on the road A B and the gain of time on B A would compensate or cancel each other, so that the swimmer would require for the whole (go and return) journey exactly as much time, as if the boats never at rest on a lake. Yet it is easy to recognise, without any calculation, that such a conclusion is inadmissible. Even in the extreme case of the swimmer's progress being exactly equal to that of the boats, the time for his double journey would be infinitely long, since he, on the outward journey, would never be able to reach his goal. And if his speed is slightly greater than that of the boats, every logical reasoner must understand, that the swimmer from A to B would require a very long time, though, of course, not an infinitely long one. And this time could not possibly be balanced by whatever time he might gain on his return journey. He will under all circumstances use more time in going out and back between two moving boats than between two stationary ones. The same reasoning holds good if the two boats are at anchor in a flowing river instead of a lake, as according to the classical principle of relativity this signifies — as far as the result is concerned — exactly the same as moving boats on a still lake.

Now let there be two boats A and C moving forward at uniform speed side by side in still water. Again a swimmer starts from

A on a go and return journey to C. In this case also he will be delayed by the motion of the boats. For if he possesses the same velocity as the boats, he would never be able to reach C at all, so that he again would in any case require more time if the boats are in motion than if they are at rest. This cross-swimmer will obviously be similarly retarded on his double journey as before.

We take one step further. We take three boats in uniform motion as arranged in Fig. 11.

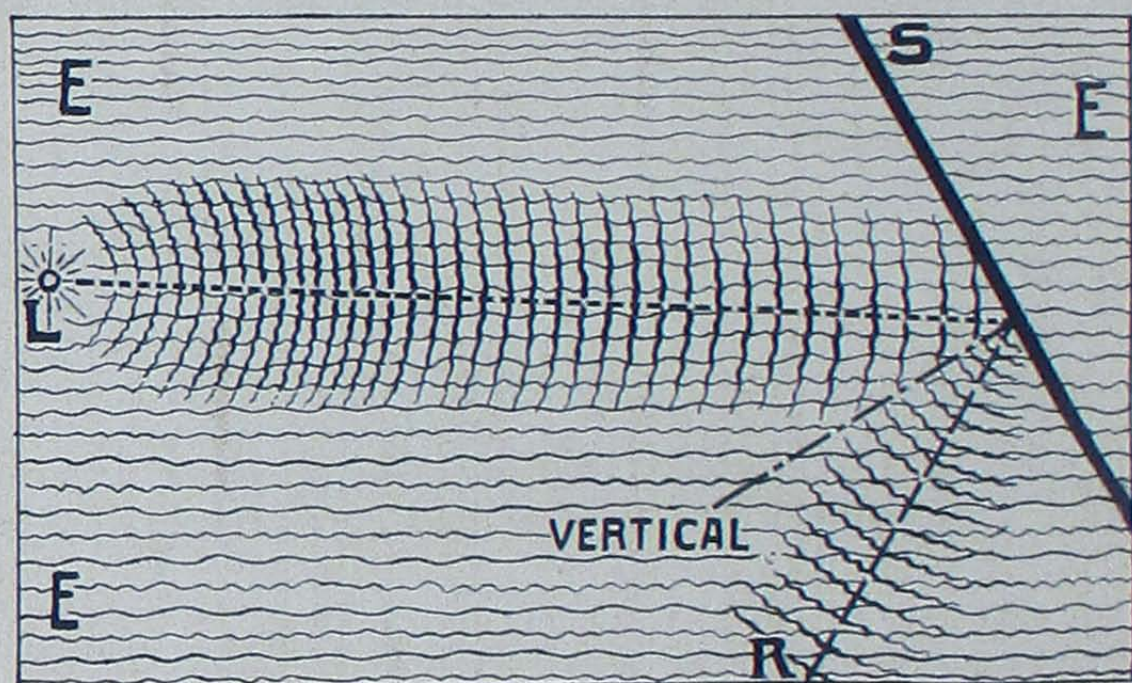


Fig. 8. Reflection of waves. S = mirror or gray-wall. L = our source of light or point of fall of stone into water. E = Ether or water in which the waves spread.

At the same moment two swimmers start from A, one to swim to B and back, the other to C and back. Fig. 12 shows how matters would stand for the cross-swimmer. While he is swimming A will have reached position A, and C will have arrived at C¹. His outward journey will, therefore, be A C¹. During his return A will reach A²; his return journey will, in consequence, be C¹ A². Calculation shows that the delay of the length-swimmer will be twice as great as that of the cross-swimmer. Here we have, of course, assumed the strength and endurance of the two swimmers to be equal as well as the distances A B and A C as being the same. The swimmers obviously can not return simultaneously to boat A, but one after the other.

Conversely, from the difference in times of their return we

conclude that the boats have either been moving in still water, or that they have been at anchor in running water. We can, therefore, say that boats and water possess a motion relatively to each other. A decision, which is actually in motion, the boats or the water, is here, of course, just as impossible as anywhere else. But not only the existence of the relative motion, but also its amount and direction can be deduced from our experiment. If we were allowed to assume the water to be absolutely at rest in the universe, the motion of the boats relatively to the water would be nothing else but their absolute motion in space. If we now let ether take the place of the water, the earth that of boat A, we recognise the instructive significance of our example. Even without mathematical knowledge we under-

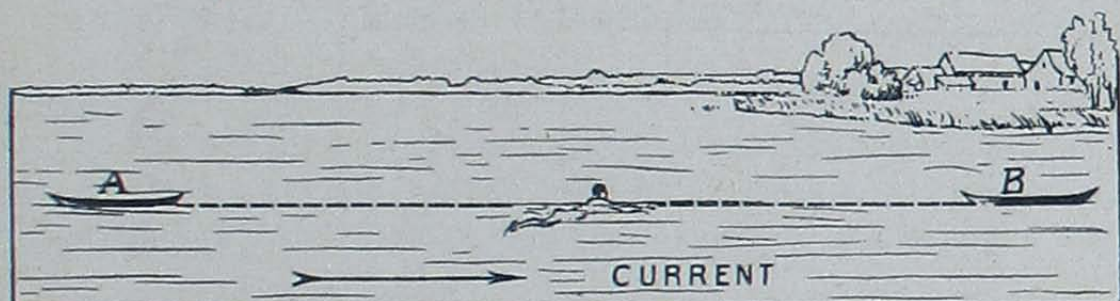


Fig. 9. Length swimmer (or straight swimmer) Either: boats at anchor and current towards the right, or boats moving towards the left and no current.

stand that the spreading of light in the direction of the earth's motion corresponds to the performance of the length-swimmer, its spreading vertically to the earth's motion, to that of the cross-swimmer. As soon as, in the case of two such rays on their go-and return-journey, differences of time occurs, the existence of a motion of the earth relatively to the ether is proved. And this motion would be no less than the earth's absolute motion, since the ether is assumed to be absolutely stationary.

We abstain here from carrying out the necessary calculations. It suffices for our purpose to have pointed out the drift of our reasoning. For not everyone who witnesses a solar eclipse is able to understand how it could be computed so accurately before its occurrence.

Now the reader is properly prepared for what follows. For the preceding discussions are indispensable for the thorough understanding of Michelson's experiment in all its bearings, and it is this experiment which forms the starting point for the modern theory of relativity. In Fig. 13 we show, omitting details,

the arrangement of the experiment which was undertaken with the object of demonstrating, if possible, the influence of the earth's motion on the velocity of light.

A ray of light issues from a lamp towards a transparent piece of glass *G* which allows one part of it to pass through, while it

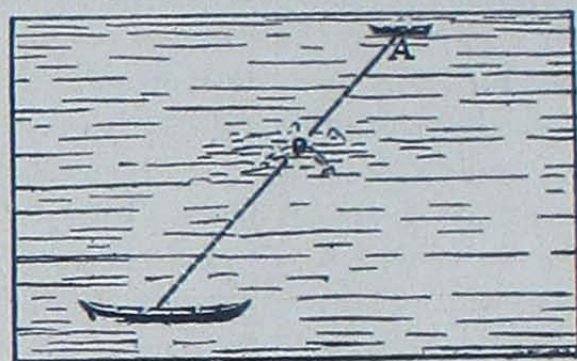


Fig. 10. Cross-swimmer.

reflects the other. This latter reflected ray meets a mirror in *A*, and is by it reflected back vertically — as it is so adjusted as to strike the mirror vertically — until it reaches approximately the same place on the glass from which it proceeds. This is the same point where the other part of the original light-ray *L* passed

through *G*, until it reached the mirror *B* by which *A* is reflected back in itself. Finally it must evidently coincide with the other ray reflected by *A*. Michelson and Morley tried to adjust the

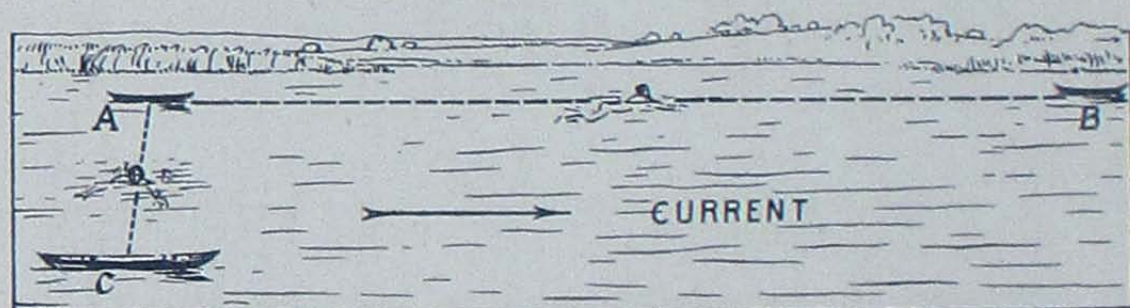


Fig. 11. Length and cross-swimmer. $AB = AC$.

direction *B G* so as to be parallel to the motion of the earth in space. Whether they fully succeeded in doing this, appears doubtful. For we know now that we are unable to demonstrate the absolute motion of a body. If the reader, watching the starry heaven some winter's night, should ask himself: whither does our journey in space really go? he would find it very difficult to recognise even the first simple relative motions, viz.

1. The motion around the earth's axis. It always points at any given moment horizontally towards the east, or towards a star just rising due east.

2. The motion around the sun. It is directed, at any time

of the year, towards that constellation in the zodiac, in which the sun appeared to us a quarter of a year earlier.

3. The motion towards the constellation Hercules (or Swan). These three motions are not equally developed, i. e. they possess different velocities. And the last, the motion which is directed into the depths of space, is still quite uncertain. It would be a considerable venture if we were to say, the direction GB coincides with the real direction of the earth's absolute motion in space. For the classical principle of relativity maintains nothing less than that we are not able to be cognisant of this motion. But from the view-point of an all pervading stationary ether we are well able to speak of a real motion. From it we can actually discover the real motion of the earth; we find that the earth must screw itself into universal space in such a way as is indicated in Fig. 14. At any given moment the motion of the earth is directed towards some definite star in the heavens.

If we now assume that it is possible to adjust direction GB in Fig. 13 so as to be parallel to the direction of the earth's motion in space, and that the experimentalists had succeeded in making

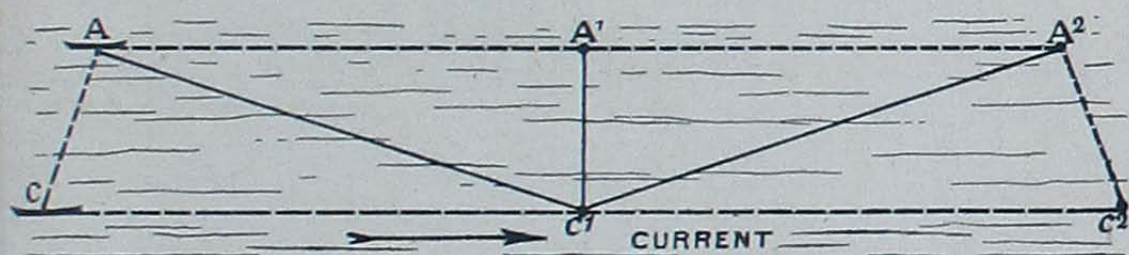


Fig. 12. The path of the cross-swimmer $A-C^1-A^2$.

it so, then a ray of light — moving in the (hypothetical) motionless ether — would experience a retardation on its go-and return-journey until it again reaches the glass G . A similar, but not equally great, retardation would happen to the cross-ray GA . The result of this would be that, at the point where these rays meet again, a certain mutual influence of the light-rays would become perceptible, a phenomenon called "interference" in physics. As a familiar instance of interference I mention the rainbow-colours we see when an exceedingly thin film of oil floats on water. Such a result should have been observable if the rays $G-B-G$ and $G-A-G$ had been retarded in a different degree.

The outcome of Michelson and Morley's experiment was nega-

tive. In no direction could a retardation of light be proved. The plane glass *G* showed no trace of interference, the expected colour-clouds did not appear. And even if the "real direction" of the earth's motion in space had not been hit off accurately, there should still have been some interference or other perceptible in every position, however slight. Yet none was observed.

It would, consequently, hardly be admissible to assume an ether absolutely at rest in space, through or in which the earth is moving. Yet another theory might still be possible; that is to say: it might be that the earth carried its own ether along with it on its journey through the world, just as it carries the air. But

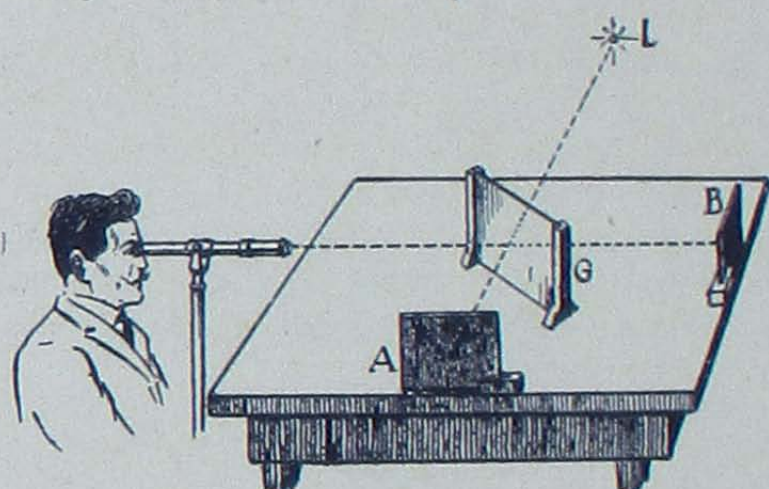


Fig. 13. Experiment of Michelson and Morley. *L* = Source of light. *A* = First mirror. *B* = Second mirror.

this would not be confined to the earth alone. The Sun in particular, also Jupiter, the king of planets, whose mass surpasses that of 318 earths would carry along an enormous appendage of ether. The sun's ether (more than 1000 Jupiters would not yet make one sun) would have to participate in its axial rotation every 25 to 27 days; the terrestrial ether would have to revolve once every year around the sun; that of Jupiter would have to do so every 12 years. How are we to imagine all these masses of ether rushing through our solar (or interplanetary) space! A silent but wildly surging sea; all the ether currents, each following its own star, whirling round and through each other in space! And as the ether is supposed to be the light carrying substance, could it be otherwise than that a ray of light passing from space through this seething, whirling ether in our solar system must describe a path varying from a straight line in every direction? That we should have an ever changing aspect of the

stellar heavens? For let it not be forgotten, that the stars we observe to-night are again seen in the same relative position exactly a year hence, though the planets, and Jupiter in particular, have changed their places relatively to ours, and would, consequently, influence the light in a different manner from to-day.

The most obvious result of the above is this: we cannot do anything with ether in this case, it fails us altogether. In fact, we have to abandon it because it does not explain the Michelson experiment. We see that an ether which is at rest, as well as an ether which partakes of the motion of the stars, is inconsistent with our experience. We must make up our minds to look upon light as a thing by itself, as an effect proceeding from hot bodies, the real essence or nature as well as the constituting mechanical conditions of which we are not at present able to recognise.

How now is the result of Michelson and Morley's experiment to be interpreted? Many men have cudgelled their brains about this question. Einstein said: we must not interpret, but accept as a fact. In this way. Let us adopt as a truth and a fundamental fact that light moves in all directions with the same speed. Let us admit as proved that light everywhere and always spreads with the same velocity.

This leads to the fourth — Einstein's fundamental proposition.

IV. The velocity of light is an invariable quantity, which is absolutely independent of the motion of the source of light as well as of the motion of the observer. The velocity amounts to 186 000 miles in a second (300 000 kilometers).

This proposition would obviously not carry us very far. Yet the further development of the thought shows, that something might and can be deduced from it. Einstein put to himself the following question: If the velocity of light is assumed to be

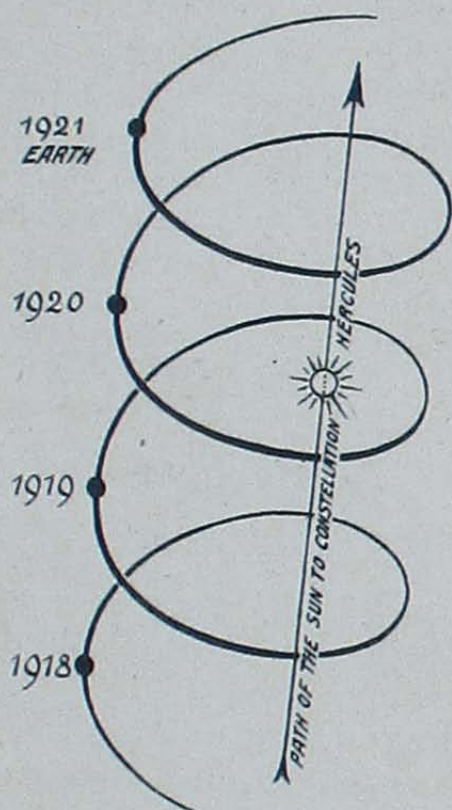


Fig. 14. The earth's path into the universe.

independent of terrestrial or cosmic motion — and if this cannot be explained with the aid of an all pervading ether — is it possible to modify our fundamental ideas of space, time and matter? Is it possible, by a suitable interpretation of these (hitherto uninterpreted) conceptions, to build up a theory with proposition IV as a foundation? What does this mean? What does he expect from us? Einstein's reasoning must have been somewhat like this. Classical physics adopted the meter, the second and the kilogram as given quantities, as unambiguous data, as absolutely existent. Is it now thinkable to admit such alterations in these definitions that proposition IV can be upheld? Indeed a question of fate. But, whatever position one may take up towards Einstein's answer to it, namely, the theory of relativity — one thing is certain: the courage that dares to formulate and put such a question at all is worthy of admiration. For as Carthesius has said: Doubt is the beginning of all knowledge.

Albert Einstein's Interpretation of Michelson and Morley's Experiment

The Dutch physicist, H. A. Lorentz, interpreted Michelson's experiment in this way. We assume the world to be filled with a stationary ether. We assume further, that the objects which move through the universe are compressed by the ether, while they push their way through it. Then we need only finally suppose, that this compression manifests itself in quite a special manner in the direction of the object's motion, in order to explain everything. We refer again to Fig. 9. The boats are in motion. We know that the swimmer from A to B and back loses some time compared to the same journey if water and boats are relatively at rest. If we now assume with Lorentz that the distance A B becomes shorter through this relative motion, the swimmer may recover a part of the lost time, since his journey has become shorter. He may gain just as much as to require the same time which the cross-swimmer from A to C requires. Here we must assume that the distance AC — across the direction of the motion relatively to the water — does not change. In this way Michelson and Morley's experiment could doubtless be explained.

Lorentz's thoughts move altogether still within the confines of classical physics. For him there exists an absolute ether as

well as an absolute motion, viz. that which takes place relatively to the ether. But the logical flaw present in all absolute conceptions is also to be found in Lorenz's ingenious hypothesis. For though we do not know the exact direction of the earth's motion in space, yet there would be some prospect of finding it out. Its determination, not by means of Michelson's experiment, would be decidedly thinkable, probably actually possible. Then we should have discovered the absolute motion of the earth in space. This, however, is incompatible with other conclusions of classical physics. Is the world, after all, not infinite? Is perhaps everything contained in it not for ever in motion? How should it be possible to find out an absolute motion in such a world? We might even go as far as doubting the possibility of absolute motion in such a world! In other words: Who can assert that any body is absolutely moving? Who can prove that it is not the whole world around it which actually moves?

Einstein interprets the Michelson experiment differently. He conceived the idea of looking upon light as quite a thing by itself, as — so to speak — the highest manifestation of the material character of the universe. As a sort of ultimate perfection in comparison to which nothing more perfect, nothing more final, could possibly be found or conceived. For did not the velocity of light appear in the Michelson experiment as if it was the same in all directions? Einstein adopted this as a fact and fundamental truth. Put in a formula.

$$\text{Velocity of light} + \text{Velocity of earth} = \text{Velocity of Light}$$

It appears at first to be nonsense. But Einstein had the courage to ask himself: is this really nonsense? What is nonsense? Surely nothing but what contradicts reality, or that which leads, out of itself, to logical contradictions with our preceding assumptions. From this viewpoint our equation, however strange it may appear, does not contain a contradiction. It is not worse than

$$5 \times 0 = 6 \times 0$$

which means, of course, that each side equals zero. And in this way Einstein's fundamental supposition is to be understood. Just as in our instance zero appears to be a special quantity in itself, which does not adapt itself simply to the rules of ordinary arithmetic, (which hold good for ordinary numbers), the velocity of light appears in the theory of relativity as a special quantity

which is not like other velocities. Here, however, I will not omit to point out, that his assumption puts at the very outset a stamp of arbitrariness on the whole doctrine of relativity. Not because Einstein has reasoned as he did, but, however he might have reached this result, this question remains for the present still an open one: Is it the only possible way out of the difficulty?

Now we must proceed to show what structure Einstein has erected on his fundamental assumption. Let us imagine two men A and B and a piece of iron together at a certain place in space. The iron is heated and commences to glow. At the very moment it begins to send out light, B leaves A and speeds after



Fig. 15. A after 4 seconds have been counted.

one of the light-rays sent out by the iron. Fig. 15 shows how matters stand a few moments after the beginning of the experiment. The observer A has remained at his place (an absolutistic expression this!) while B has hastened after the light. How he does this, does not interest us, yet Fig. 15 is meant to suggest that he travels at considerable speed. Let us assume that we remain at rest with A, and that 4 seconds after B's start, the position A—B—L has been reached. A has determined the distance of the head of the light-wave (L) at 1 200 000 kilometers or 746 000 miles: we, standing near A, measure, the distance of B from L and find 800 000 km or 497 000 miles. In order to obtain a value for the velocity of Light A naturally divides the observed distance of 1 200 000 meters by the time elapsed, and finds it to equal about 300 000 m or 186 000 miles. This is the velocity of light observed by A. A similar division must now — at the same moment — be done by B, who also wants to find the velocity of light. He measures his own distance from L and obtains for it the same value of 800 000 m (497 000 miles) which A had found (see proposition II). This he divides by the time elapsed, i. e., as he observes simultaneously with A, also by 4 (seconds). His

value for the velocity to be derived will, therefore, equal $800\,000:4$ or $200\,000$ m. This, after the experiment just made by A, cannot be true. Neither does it agree with Michelson's experiment. And yet it is perfectly clear, that the observer B, at the special moment, was nearer to L than A, and as he also divided by 4, he could not but arrive at a smaller value.

But wait! If A, B and L were at first at the same point in space, and after 4 seconds the order as in Fig. 15 existed, who will guarantee that it was A who remained at rest, while B was moving? Could not A just as well have moved towards the left and B have remained stationary? That it is impossible to decide this question, we have already learned from proposition I. B might say, A and L have run away from me in opposite directions. In Fig. 16 just 3 seconds may have passed. B quickly determines



Fig. 16. B after 4 seconds have been counted.

the distance of L and divides the number obtained — $900\,000$ km or $559\,000$ miles — by 3 (seconds) and finds $900\,000:3 = 300\,000$ ($186\,000$ miles) per se, or the well known velocity of light. A, however, at the same moment, divides the distance found by him, namely $1\,200\,000$ km, by the same number of seconds and obtains for the velocity this time $1\,200\,000:3 = 400\,000$ m ($249\,000$ miles) which does not tally with B's result. And yet it appears quite clear that, at that special moment, A was further removed from the head of the light wave, so that he had to arrive necessarily at a larger value. Here lies obviously a serious difficulty, which is likely to baffle the reader. In order to remove it, an inspiration (let us say) is needed such as occurs only now and then at special epochs in the development of a science. Einstein had this inspiration. But his way out of the difficulty is only one way among many, not necessarily the only possible one. Einstein asked himself: what does it really mean, when I say, two observers determine simultaneously — i. e. at the same absolute moment — the distance of their respective places from the head L of the light-wave? What is the meaning of the word simultaneous, when the two observers, for whom the same moment is meant, are far removed from each other? Simultaneousness or synchronism presents evidently some inherent difficulty, which the author already felt in 1904 (when the theory

of relativity had not yet arrived) and which he discussed with Einstein, — then a minor official at the patent office in Bern.

But we will not worry over the nature of a simultaneousness "distributed" (so to speak) in space. We simply ask A and B to be good enough to provide themselves with such watches, as are adapted to our special purpose. If then, in the case discussed (Fig. 16), B's watch showed the lapse of 3 seconds, A's however, at the same moment 4 seconds, we should have for

$$\begin{array}{l} \text{A: } 1,200\,000 : 4 = 300\,000 \quad \text{and for} \\ \text{B: } 900\,000 : 3 = 300\,000 \end{array}$$

or both would arrive at the same value for the velocity of light.

We simply must insist on the times for A and B to pass in such a manner, that the desired result — the same value for the velocity of light — is obtained by both. In doing so, we do away with an old and dim conception, that of simultaneousness; we throw it simply over board. Instead we have one passing of time which holds good for A, and another which holds good for B. If the reader has understood the matter, the only problem yet remaining is this: whether it is possible to modify the passing of time for A and B in such a manner, that the same velocity of light is found by both observers. This is a problem for the art of the computer. I have reduced it to comparatively simple form in an article published in the April number of the German periodical "Kosmos" for 1920. Here we are only concerned with the fact, that the solution of the problem is possible. The passing of time becomes relative, i. e. different for each observer, so that each arrives at the same value for the velocity of light. This is the fundamental principle, the source of the doctrine of relativity. But something unexpected showed itself here (perhaps some of my readers have already suspected it) namely, that the distances AL and BL appear of different length, according as they are seen and measured from A or from B. And yet it is one and the same length. It proves to be quite impossible to modify the passing of time by itself and altogether independently of everything else, so as to satisfy Einstein's proposition IV. It depends for each observer rather on the speed at which he travels through his distance, or in other words: the passing of time depends on the relative velocity between A and B as well as on the velocity of light. The above divisions — adopted for the purpose of an easier explanation — are, therefore, not correct

from the standpoint of the theory of relativity. For (Fig. 16) the distance AL was found to be 1 200 000 m from B's standpoint and was divided by A's time, by 4. More exact calculation shows, that the observer A finds a different value for the same distance AL. Our task must be to modify, to arrange both quantities — lengths or distances and times — simultaneously and in connection with each other — in such a way that the principle of the invariability of the velocity of light is satisfied. For we can assert positively, that this will lead to a logically possible system of physics. It is only necessary to abandon the belief in the absoluteness of time and in the invariability of the distance between two points for all observers. To reconsider and part with such long received conceptions of classical physics will naturally require a heavy mental effort for each of us.

Fifth proposition:

V: If the velocity of light in space is to be an invariable quantity, distances of time and space must lose their absolute character and become relative, i. e. dependent on the relative motion of the bodies in the universe.

The non-existence of absolute space and absolute time is a conception, which might easily follow from sober practical reasoning. Because we are not disinclined to approve of the general thesis: *n o t h i n g* is absolute. But if we accept the principles that all distance, whether in space or in time, are relative, Einstein's theory does not by any means follow. For philosophical insight never leads to physical doctrine. Not even the invariability of the velocity of light could be linked up with the conception of relativity in general. It is essential to state, that Einstein's doctrine is a great deal more than an "ancient truth". It forms a very special method of removing the innermost contradictions of the classical conceptions. This is done by the extension of relativistic, and the practical abandonment of absolute thoughts. It is therefore, a development, a very unmistakable development, in the direction — already existing — of superseding the fundamental principle of the absolute. Newton already recognised that there is no absolute orientation possible in space, though he refrained from expressing it. The development is well shown by the following juxtaposition.

Newton considered

Situation of a point in space	}	as relative
Situation of a point in time		
Velocity of any motion		
Length of a distance	}	as absolute
Duration of an event (periods of time)		
Acceleration of a motion		
Dimensions of a body		

The special theory of relativity considers

Situation of a point in space	}	as relative
Situation of a point in time		
Velocity of a motion		
Length of a distance		
Duration of an event		
Dimensions of a body		
Acceleration of a motion	}	as absolute
Velocity of light		

The name "special" theory of relativity refers to the following. In 1905 Einstein wrote a short treatise in which he formulated the fundamental thoughts of his doctrine. He introduced in it the idea of relativity of time and proved the usefulness of the new theory by a series of decisive calculations. Still, as the reader has seen, a certain residuum of absolute conceptions yet remained, before all the invariability of the velocity of light for every observer, whatever his motion in space. But the acceleration of a motion also remained — at least apparently — absolute, a fact to which we shall have to refer later on. This theory of 1905 was since further extended. For nobody can avoid thinking, that a relativity, which still contains some absolute principles, cannot be held to be fully developed. Such a development Einstein attempted in 1916 in the shape of the "general" theory of relativity, to differentiate it from the "special" one of 1905.

Let us now try to penetrate into the deductions which follow from the special theory of relativity. This theory is very important for our proper understanding of the world, not only because it shows further conceptions, hitherto deemed absolute, to be relative in reality. It is instructive not only, because it has shown us, that we, unsuspecting, have taken a variety of notions to be

absolute and real, while yet our general interpretation of the world inclines towards looking on everything as relative. What has rather made this special theory of relativity a turning point in physics is this, that it connected space and time with each other. One could indeed have called the whole doctrine not improperly the "principle of connection" (or of linking together). For to the classical physicist space and time are not only absolute but also independent of each other. Fig. 15 shows that the time of B, if we ascribe to him different velocities in succession, would pass by at (successively) different speed. Of course — and this must be distinctly understood — time as an uncertain somewhat hazy something existing in the universe, is not relative; only the passing-by of time, as expressed in the length of the second, depends on the motion of the observer. To explain the matter from yet another viewpoint we may say: The ideas about the essence of time held hitherto presupposed a vague cosmic process, which means absolute time. We never were able to understand, much less to measure this time. Whatever its real nature may be, we have advanced so far as to replace it by another abstraction which we also call time, and which is to us of special value in the interpretation of natural occurrences and conditions. You may look upon this kind of "time" as a purely mathematical notion if you are so inclined.

Now one can also adopt an extreme position and say: there is no absolute time. This is not to mean, that a single moment of time can only be fixed relatively — this appeared already to Newton as self evident —, but it is intended to be a short formula for: the duration of any event cannot be fixed absolutely. Quite similarly the phrase: "Space is relative" is in itself a very indefinite statement. If we mean by it, that the location of a point in space cannot be fixed absolutely, we only state what was already known from Newton to Mach. The modern theory of relativity, however, means by it, that the distance between two points in space, i. e. the length of a staff, is not an absolute quantity. It rather depends on the condition of the observer of this distance with regard to the distance itself. Hence the modern theory of relativity assumes the duration of an event and the length of a rule to be quantities of relative value. This is something quite new in comparison with the fundamental view of classical physics. The statement "space and time are relative" has now-a-days always the modern, the new "Einsteinian"

meaning. And here it is practically a matter of indifference; whether we say: "There is no absolute lapse of time" or: "It is true that an absolute time exists, but since we cannot do anything with it, since we cannot understand it, we must necessarily abide by the relative time as the only one which can be physically ascertained and verified.

We saw that the principle of relativity is essentially also a law of connection, inasmuch as it combines space and time into one coherent (undivided) whole. And as space, for any definite point, is defined as length, height and breadth, the theory adds to these "time" as a fourth coordinate. The following reasoning results. Space certainly is three-dimensional, but space is not the world. This world is represented by the continuum space-time, i. e. it possesses four dimensions. One need not try to form a mental picture of it, for it cannot be realised by our senses. Just as little, perhaps, as the "square of time" which occurs in many physical formulae. This four-dimensional world was "invented" by Miskowski; it means a new step on the way towards the unification of our conception of the universe.

The stage of real events (not of geometric propositions) is not the good old (and yet so vague) space, but this theatre of happenings is a world of four dimensions. We used to imagine space as a silent and abstract scaffolding, which just exists, while time appeared as an eternal flowing which signified the succession of events. If we now want to picture the world to ourselves according to the theory of relativity, we must weld space and time together into one "continuum". The "bring" and the "becoming" must form one unit together. Our world knows no points. What moves is not a geometrical point, but simply a body. And as the "linking-up" of space and time happens through the motion of a body, it is obvious that this connecting together is due to matter. The principle of relativity contains, therefore, much more than only the uniting into one of space and time. It also involves the mutual concatenation of the three categories — or fundamental abstractions — of human thought, of space, time and matter.

Before we carry this important discussion any further, we must mention another immediate result of Einstein's investigation of 1905. The length in time and the length in space are modified so that the velocity of light proves invariable; lengths in time and space become mathematically connected. The velocity of a

body will, consequently, also have to experience a different evaluation. The proportion

distance described divided by time employed

will change the value it had in classical physics, since distances in space and in time are not intimately connected with — or dependent on — each other. And thus we perceive that the proposition of the combination of different velocities by simple addition cannot be true any longer. A small loss must show itself against the simple arithmetical sum. If a train travels at 20 m per second, and a traveller by this train moves 2 m per second in the same direction, classical physics assumed his velocity in space to be 22 m per second. The theory of relativity shows, however, that this is no longer the case as soon as the new conceptions are introduced. The resultant (compound) velocity, will always be less than the numerical sum, because the new doctrine is based on the impossibility that the velocity of light can ever be exceeded. It is the one extreme velocity which may — perhaps — be reached, but than which no greater velocity can ever exist. It plays the same part in natural philosophy as the abstraction "infinity" in mathematics. Just as "infinite + 5" means as much as "infinite + 7" — namely just infinity, "light-velocity + (or —) earth-velocity (30 km per second) produces just again light velocity or 186 000 miles (300 000 km) per sec."

In other words we have the new proposition of addition:

VI. If a body possesses two velocities in the same direction, it moves with a resultant velocity which falls short of the arithmetical sum of both. The greatest possible velocity is that of light.

There lie, no doubt, two unsatisfactory limitations of free thought in this proposition. The first was changed by Einstein in his "general" theory of relativity of 1916, when he showed the velocity of light to be variable in the neighborhood of great masses. The second, however, remains. In the "general" theory also the velocity of light can never be exceeded. We are, in a way, able to guess at the existence of such an upper limit. If I ask how quickly can I turn a wheel? many a one might answer: as quickly as you like. Yet this is evidently not the case. A wheel can only be turned as long as it hangs together. When a certain speed is exceeded, it is torn asunder by the centrifugal-force.

This example is closely related to the matter under discussion. For the speed-limit, if really existent, must follow from the property of matter in the world. One might reason in this way. The heat in a body is understood to be due to a motion of the component parts of the body. If now the process of heating is continued, this motion becomes quicker and quicker; at first

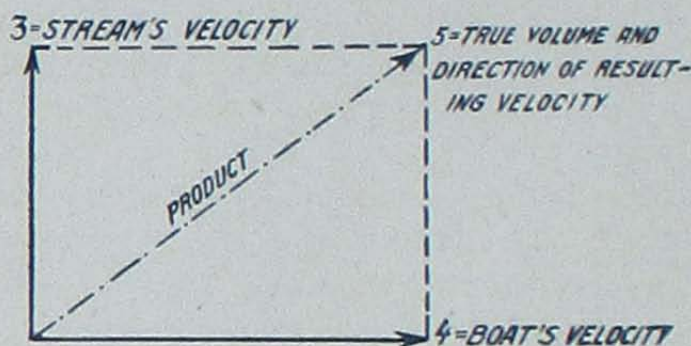


Fig. 17. The classic construction of the parallelogram of velocities.

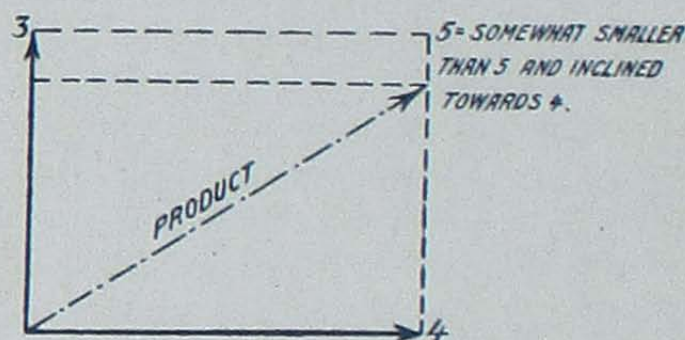


Fig. 18. The relativistic construction for an observer moving towards the right.

the body becomes liquid, finally gaseous or volatilized. If the temperature rises still further, the molecules are split up and the atoms appear as free bodies, which must be imagined to be in very violent relative motion. Now one might expect (by analogy) that still further heating might force the atoms themselves to break up and to lose their material character; might make them split up into electrons, i. e. into the smallest thinkable particles which have been observed in electrical radiation. These also are in very quick motion, over 100 000 km (62 000 miles) per second. Now we must make one more bold step in advance. We assume that finally these electrons also fall asunder (though this has as yet not been observed) and that the result of this ultimate subdivision is light — the last known manifestation of matter. Its velocity would, therefore, be the highest producible in the world. — All these hints are only intended to show that an upper limit of speed might well be introduced into a serviceable system of physical thought.

Proposition VI is only a special case of a more general one which refers to the parallelogram of velocities. This well known and popular construction also is no longer valid in all exactness, if the propositions of relativity are adopted. But it must at once be

the body becomes liquid, finally gaseous or volatilized. If the temperature rises still further, the molecules are split up and the atoms appear as free bodies, which must be imagined to be in very violent relative motion. Now one might expect (by analogy) that still further heating might force the atoms themselves to break up and to lose their material character; might make them split up into electrons, i. e. into the smallest thinkable particles which have been observed in electrical radiation. These also

explicitly added that the deviations of our modern interpretation from the old one cannot be perceived in ordinary experience, as only in the case of very high velocities practical consequences of the theory of relativity can ensue. And a velocity is a high one, when it ceases to be negligible in comparison to that of light. The earth's velocity — 30 km per second — is so far the greatest velocity we are familiar with. And this is only the $10\,000^{\text{th}}$ part of that of light. Or, in other words, this greatest of all relative velocities amounts to no more than one percent of one percent of that of light. All other terrestrial velocities are still very much smaller. It is because the every-day world of our experience happens to be constructed in this way, that we could assume time to be absolute. It is also the reason why we could consider distances between points as absolute quantities. It also enabled us so far, for the purpose of technical application for instance, to "carry on" with the classical construction of the parallelogram of velocities.

Matter and Force Form a Unit.

Nature presents in the endless change of phenomena a confusing picture of relations between all things which exist or have existed in space and time. One might say: everything depends on everything. It is a peculiarity of our standpoint with regard to natural happening, that we must have a cause for every occurrence. If a slate falls from the roof, it must have been loose. The slater did not drive that particular nail sufficiently far, because he had a worrisome thought in his mind: he was to lose his job next day, because the business was to be dissolved on account of the death of his master. For this and many other reasons the slate fell three years later on the hand of a passing girl and injured her thumb so that she could neither draw nor write for some weeks. — We could, of course, string an unlimited number of further relations on this chain, and should gradually find that the one single occurrence is really somehow connected with all others. Here we can distinguish three groups of events, which show a certain orderly sequence with regard to the original single incident (a slate falls from the roof) viz:

1. Those preceding events which can be brought into direct relation with the single incident. This is the chain of causes.
2. Those following events which are influenced by the single

one. These are the chain of consequences. These two lines of causes and effects intersect in the one special point in space and time.

3. Those events which, though not directly related to the single incident, are yet related to the causes and consequences as further causes and effects. (Perhaps in some such way as I, though not a blood relation of my brother-in-law, am yet a blood relation of blood-relations of his.

And since any event whatever may be the special one chosen or singled out for consideration, the machinery of the world is ruled by an incomprehensible intermingling of such chains of relations. If one wants to understand thoroughly any single event in our world, one must include a very large number of other occurrences in the investigation. As a rule this way only remains open to us: to ascribe most occurrences to chance. That which has so many causes that our mind is unable to grasp them, is looked upon as accidental. That the slate just hit the girl as she passed the house (or rather that the girl just passed the house when the slate fell); that it injured her thumb and did not fall on her head — all this is chance. It is true, I know, that the girl always walked along the gutter, that she was in the habit of waving her right arm; but this only shows, that every phase of the occurrence and every detail appear to the conscientious investigator as well founded.

Let us now disentangle from this bewildering maze the purely physical fact: the earth "attracts the stone" as we thoughtlessly say. The stone takes a definite time to reach the ground. It breaks up into a number of fragments which, taken together, possess the same weight as the original stone. Now, scientific reasoning is nothing else but the eager search for laws in nature. A bold undertaking indeed, in the face of the intricacy of natural events. A law appears in its simplest form, when it expresses the unchangeability of something in the flow of happenings. As the German poet says; the law is "the resting, fixed, pole in the flight of events". And it is an instance of the generally prevailing law of the "conservation of matter", if the weight of the stone, in spite of the change of its form, remains unaltered. Matter in the world forms an unchangeable stock or store; it can neither be increased nor can it be reduced according to this law. If, some day, I find a brick lying on my desk, it would never enter my mind, that it could have arisen out of nothing. And I should never

dream of thinking, that it could again vanish into nothing. Mechanical and chemical influences may, of course, change its shape and form, may embed it into other matter; but it can never be put an end to, it can never be really removed out of the

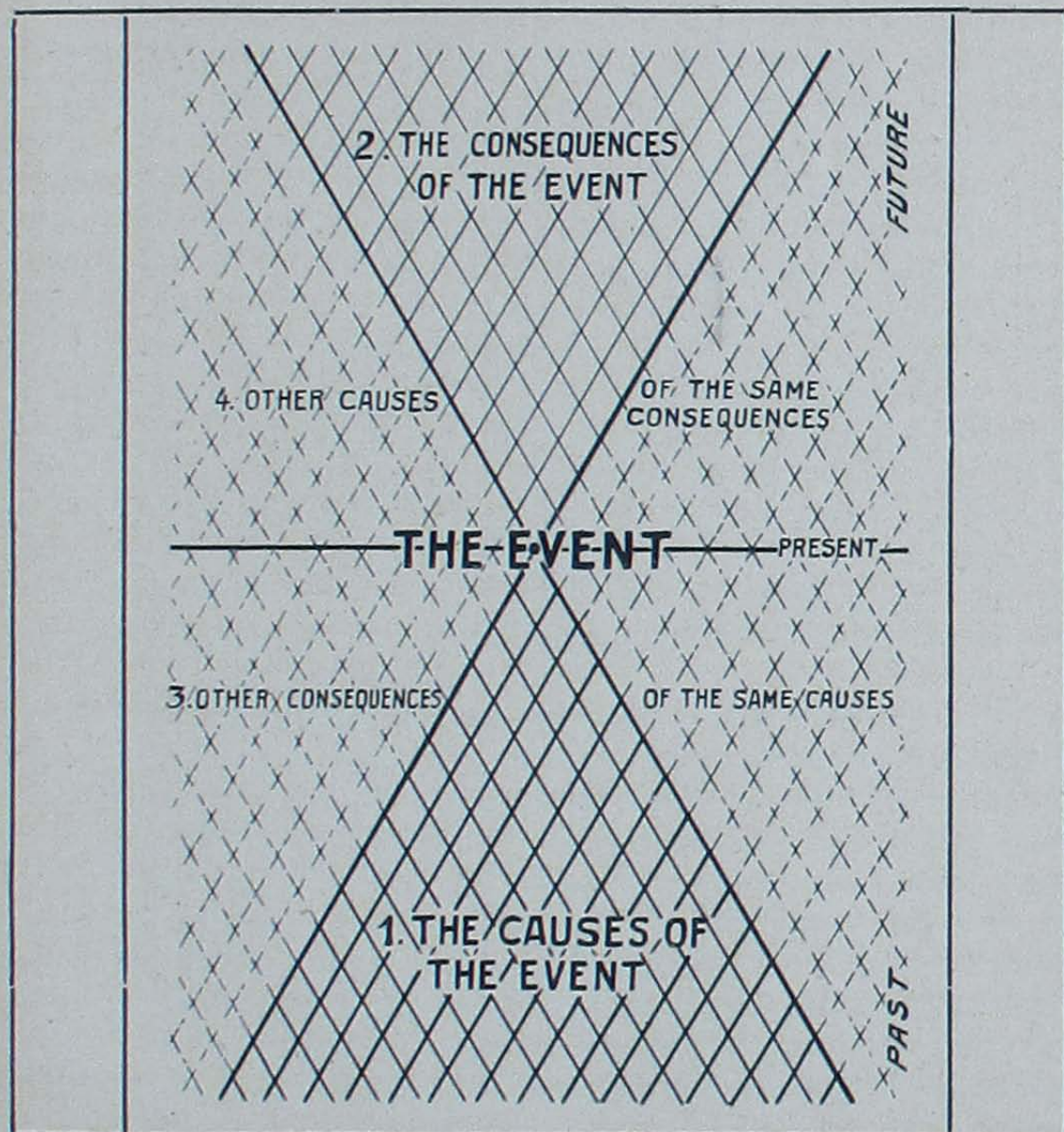


Fig. 19. The place of a single event in the endless flow Cause-Effect. The lines indicate the paths of energy through the world. Where two such paths intersect, an occurrence takes place. The events in the lower triangle (with drawn out lines) are "causes"; those in the corresponding upper triangular field are "consequences or effects" of the event under consideration, which forms the centre of the drawing.

world. Matter is just as far from ever arising out of nothing as human life itself. To our human understanding it has just always been there.

We can test the law of the conservation of matter with a pair

of scales. The law seems to hold good as far as the sensitiveness of the instrument goes. — But in order to be quite strict, we must decline to assume it as being absolutely valid. It is further quite inadmissible to apply this law to the infinite universe. For if, according to the tenets of classical physics, the world is really infinite and contains an infinite number of bodies which, in the aggregate, represent an infinite quantity of matter, there is obviously no sense in saying: this quantity is invariable. Such a statement can only be applied to finite or ordinary numbers and quantities. If I shut off my room from all outside influences if it be possible, I might pronounce the law: the quantity of matter within this room is unchangeable. Thus the law of the conservation of matter is only an idealization of practical experience, to define it quite accurately. An idealization which may prove not quite free from objection. Nevertheless, we are well contented to have this law as at least one sign-post through the chaos of events. It has frequently been said, that it is the object of natural science to derive all phenomena from this one fundamental thesis. We are to-day still very far removed from being able to do so; on the contrary, we have a large number of different laws, which do not appear to be connected with each other.

The general philosophical perception, that everything "flows" is pushed somewhat aside by this law of the invariability of the quantity of matter. And yet there exists yet a second similar law which also expresses an unchangeability within terrestrial and cosmic happening. Namely, the law of the conservation of energy (or force, where force just signifies "energy" or "work done"). This law, discovered by the German physician Julius Robert Meyer in 1843, lies still less on the surface of events than the preceding one of the conservation of matter. If we wind a clock by lifting certain weights, we perform some work which can be expressed in kilograms. In this way. If we lift a clock-weight of 4 kilograms to a height of 2 meters, we perform work of 8 kilogram-meters. In return the clock will be kept in motion, will "go", for some days. For that period the wheels will turn in spite of friction. The pendulum also will receive a continuous number of small impulses during that time. The friction on the spindles and against the air will generate a certain amount of heat, which is the final trace — quickly dissipated — of the energy put into this system, the clockwork. On the other hand,

the work at the beginning of this chain of consequences, 8 kg. m., has its source in my muscles, in which a certain chemical change — perceived as fatigue — occurs. This represents the equivalent of the 8 kg. m. Here we have again a veritable chain of events. Leaving all other questions aside, we confine ourselves to the different forms of energy which change into each other, viz. chemical energy, mechanical heat and work. The law of the conservation of energy maintains that the sum of energies contained in a complete, circumscribed system is invariable. Thus energy also can neither arise out of nothing nor vanish into nothing. If we imagine all energy taken together, if we also include electric and light-energy, the world must have a certain stock or store of energy. That is the "wealth" of the world. These energies can change into each other; p. e. mechanical energy can change into heat as we saw before. But there is no possibility of bringing about a quantitative change of the whole store. This very general wording is again too general. For if the world is infinite, and if all energy is infinite, there can be no sense in saying: the energy is (in quantity) unchangeable, for

$$\text{infinity} + 5 = \text{infinity} + 7 = \text{infinity},$$

i. e. if an infinitely large quantity is increased, it remains what it was, namely, infinitely large.*)

Thus we find that traditional natural philosophy pronounces two laws of conservation to be valid within a system which is confined to itself and unconnected with the outer world, viz. the law of the conservation of matter and that of the conservation of energy. The latter of these laws can be put into this form: It is impossible to construct a machine which keeps performing work, without a constant supply of energy being put into it. (perpetual motion is impossible). Now it must be said that these two laws in no way suffice to explain exhaustively even the simplest events. When for instance, I lift a body up, I perform a certain amount of work in the system body-earth. Those two laws affirm, that the body does not change its quantity of matter in the process, and that the energy imparted to it can never disappear tracelessly. If, however, we had a law that every body did increase its temperature (ever so slightly) by being lifted up,

*) Conversely the above shows that human understanding finds it easier to conceive the universe as something real or finite, than as something infinite.

then this heating would suffice to satisfy the law of the conservation of energy. If, therefore, we lived in a world in which a body could be heated by lifting, there would be no necessity of this body ever falling down again and parting with the energy stored up in it as momentum or impetus in reaching the ground. It might remain suspended, since the equivalent of the work performed would already exist as heat. Now it is true; that our world is not constructed in this way. Yet numerous other possibilities are not fulfilled in the reality we know. These two laws of conservation do not enable us to "predict" anything.

All natural occurrence is an uninterrupted wandering of natural energies (heat, electricity, light). But this wandering requires, in the sense of classical reasoning, a carrier; heat is always in a body, also energy of motion. The energy of light also is (in the classical sense) either moving matter (theory of emission) or energy of motion in ether. In short: energy does not exist by itself in the world, not — so to speak — naked. The instance of living force, or energy of motion, will make this very clear. A ball at rest — at rest, of course, only relatively to us — cannot perform any work by changing its condition of motion; while a moving ball can do so by diminishing its speed. The whole of the mechanical work which can be performed by consuming the motion of a body, is called "kinetic energy" or "living force" of the body's motion. We can, therefore, well imagine a body (this is an important point in traditional thought) which possesses no perceptible kinetic energy; but we cannot imagine a kinetic energy not attached to a body or existing free by itself without a carrier. Thus every occurrence, wherever it may happen, appears to us as a change of energy in bodies. The entirety of natural processes (there are no other!) appears to us in fact as an eternal wandering of energy through the different bodies in existence. Here we must amplify the meaning of the word energy by stating: all energies can only be kinetic. Thus the heat in a body has long since been found to be kinetic energy of moving molecules. And we are convinced that all other energies are also in reality kinetic. We know, for instance, that a small piece of dynamite contains a great capacity of performing work. How does it do this? Evidently in this way. The elementary constituent parts of the substance are in violent motion, perform — so to speak — a mad dance, within their molecular connection. But as soon as this connection is destroyed, i. e. as

soon as the dynamite is brought to explosion, this molecular motion becomes liberated and free to perform work of a coarser kind; namely, heat and motion. This conception is already to be found in traditional physics. The term "potential energy" is only a descriptive one; it gives no information about the real nature, the essence, of the pent-up natural force. But even the idea that all energy is kinetic — though it supplies one, single, fixed standpoint —, is in itself not very intelligible.

Fig. 20 shows a weight of 5 kilograms lifted to a height of 2 meters. It is placed on a table and held so that it can be made to fall down by a slight "release". The work done by the lifting is contained in that weight as "potential energy". This form of potential energy would be called energy of position. How the energy is stored and packed away in the body, we are not told by its name. But as soon as we assume that potential energy is in truth kinetic, is the energy of motion of invisible particles of the body, a vista into the actually possible facts is opened out to us. But how strange, how unwonted, are the conceptions required! By lifting the body (we must assume) some-

thing in the arrangement of its smallest constituent particles must change, some motion must increase in speed — in such a way, that the equivalent of the work performed by lifting must be hidden in the matter! And when the body falls — which may be brought about without any jar by means of the release — this superadded motion must again spend itself. These are necessary, though unaccustomed thoughts, to which we are forced by the unflinching adherence to the principle that all energy is kinetic, or: that everything which happens is ultimately a manifestation of motion.

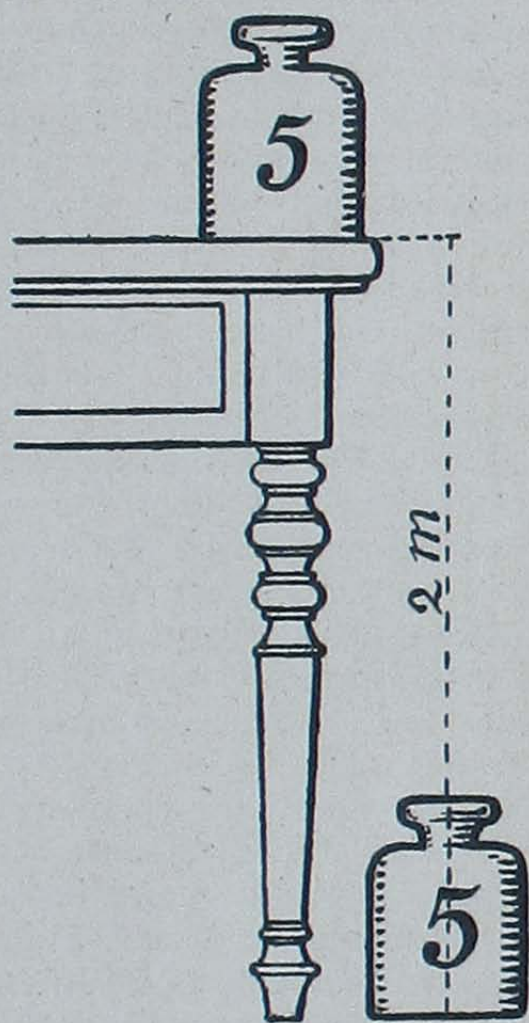


Fig. 20. The lifted weight has potential energy.

If the reader has taken his full share in all this reasoning, his mind is now prepared for the new great doctrine which has been deduced from the theory of relativity. This theory has solved the problem: how are matter and force connected with each other? With the exception of the great thinker and chemical analyst Ostwald, who touched on this delicate point occasionally, nobody in physics ever put this question.

The modern theory of relativity arrives at the result, that matter is nothing but motion! This conviction arose in this manner. At first it was seen, that energy in the form of motion possessed the qualities of inertia and weight. And since these two qualities are two fundamental characteristics of matter, the identity of energy and matter soon followed. It seems a harmless conclusion, and yet a thorough preparation is necessary for its understanding. The above reasoning shows very clearly, that the new conception lay unmistakably in the direction of the preceding development. What we learn is nothing new in principle. Rather: what hitherto was only occasional dim conjecture, becomes now a well founded possibility. A pile of substance, even in the sense of classical physics, possesses some energy, though it lies at rest on my table; for it has its own latent heat. If it is deprived of that heat, it loses its energy. Each body has some lowest temperature at which it ceases to hold any perceptible energy (according to the hitherto prevailing theory) and becomes merely an inert mass. Yet if I lift up a body in this condition, something must take place within it, though we are unable to perceive it. According to the relativistic theory, however, a piece of matter, though cooled down to the lowest possible temperature, lying before me on the table, must possess an immense amount of energy, well concealed — it is true — in its inmost structure. In this way we could understand the true facts of the case still from the standpoint of the classical doctrine. Yet the new theory of relativity goes one step further. Instead of saying: the matter has energy, it pronounces: the matter is energy! Matter is the highly concentrated form of the innermost bodily energy. This energy is hidden so deeply within the body, that it appears hopeless ever to be able to release it. The radiation of radium seems to be the only, unique, manifestation we have so far discovered out of the depths of the interior of matter. Radium is able to send out heat and light rays year in, year out, without a diminution of its weight becoming perceptible to us.

The chain of relativistic reasoning would be this. A large quantity of energy represents a very insignificant amount of matter. Conversely, out of a minute, immeasurably small quantity of matter an inconceivably large amount of energy might be obtained, if we only knew how! According to Einstein's formulae the energy to be "got out" of a given quantity of matter is expressed by the amount of matter multiplied by the square of the velocity of light. Thus it can be shown that in a kilogram of any matter, whatever, work of a thousand million of millions kilogram-meters lies hidden.

In one direction this reasoning must yet be supplemented:

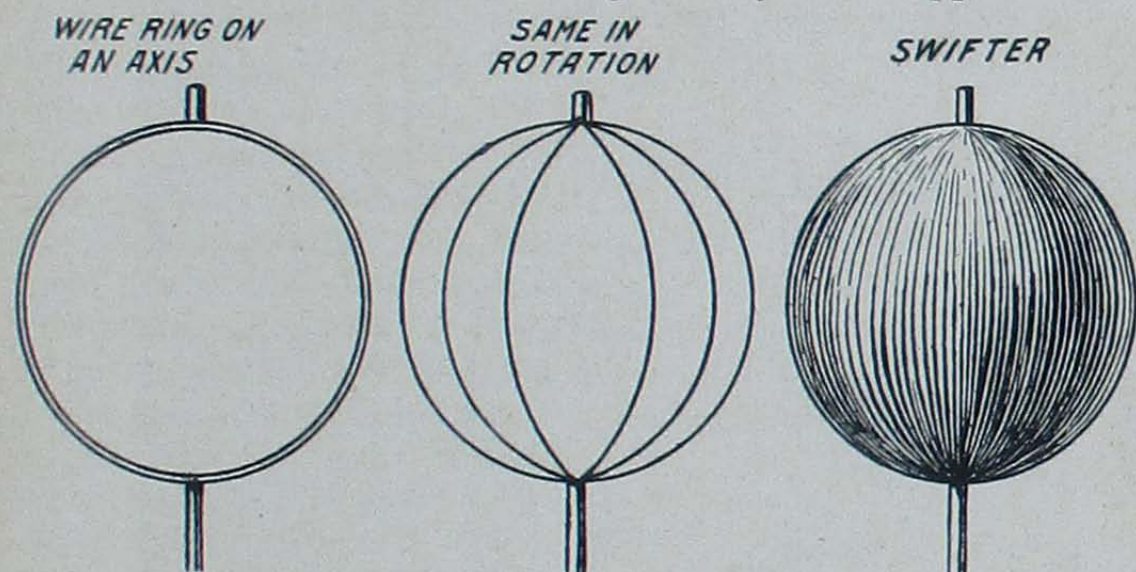


Abb. 21. A "physical" spherical surface. (An illusion brought about by rotatory motion.)

For even [classical] physics had yet to ascribe chemical energy to a body at its lowest temperature, the nature of which energy was as yet unknown. A piece of any explosive, for instance, must still contain — even at its lowest temperature — the force stored up in the structure of its molecules. And from here onward the conception of the theory of relativity again appears as a logical further development. We need only assume the atom also to possess a complicated structure, to be built up of movable component particles, in order to gain at once the treasures which lie deeply hidden in the interior of matter. Thus we have four forms of energy.

1. The visible energy of motion, the "living force" of matter.
2. The invisible energy of molecular motion, or heat.
3. The invisible energy which consists in the motion of the atoms within the molecules, or chemical energy.

4. The invisible energy which lies in the motion of the electrons within the atoms.

The view, that the atoms of elements are not small spheres, but that each of them by itself forms a complicated system somewhat like a solar system, has been arrived at quite independently of the theory of relativity. It enables us to realise the immense amount of energy which is hidden in matter, or rather which is matter.

In conclusion we must yet make a series of observations which are important for the understanding of the problems in hand. The following will serve as an introduction.



Fig. 22. A bar or staff of molecules. (Ideal enlargement about 50 million fold.)

If we put a wire hoop (Fig. 21) into very quick rotatory motion, it will soon appear to our sight as the surface of a sphere.

To the sense of touch also the illusion of a continuous spherical surface will be presented. If the speed is sufficiently high, light also will behave towards this system in the same way as if it was an actual sphere. Finally no possibility will remain to us to distinguish such a rotating system from a real globe, as all means

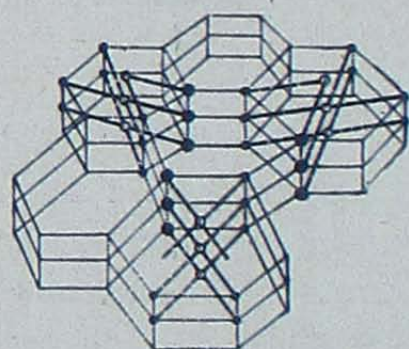


Fig. 23.

Fig. 23. Imaginary view of a molecule of calcite.
● = calcium; • = oxygen; ○ = carbon.

The continuous lines serve only to produce a spacial impression. The dotted lines indicate the combinations of the different atoms. The imaginary view represents the formula CaCO_3 , taken nine-times. By the contiguous grouping of equal atoms the molecule becomes larger. In the case of crystals, we may assume that the whole visible volume of the crystal is occupied by such lattice-like systems. In gases such a connexion, which holds all molecules together, does not exist. In all cases the main or essential space within a molecule is — empty!

to separate the successive positions of the hoop from each other will fail us. A system of this kind, provided it rotates with sufficient speed, is to us really the same as a continuous spherical surface. It is illusive, it is an effect of motion, not something bodily existent. Similarly, if a body moves in a circle with very high velocity, this will ultimately be to us the same as a continuous circle, or rather as a continuous bodily circular ring (a "torus" so to speak.) Or if between two ends A and B an immense quantity of excessively small bodies are moving to

and fro at a terrific speed, — this world of rushing particles will be to us nothing but a rigid staff or bar!

These facts render us somewhat suspicious towards all appearances in general. Let us — armed with this suspicion — consider a piece of iron which we hold in our hand. It appears to us as a continuous, compact, solid reality. And yet we know that all bodies consist of molecules, between which must exist considerable interstices within the matter. We even know that the space of all these interstices must be longer than that filled by all the molecules taken together! Let us reduce the size of

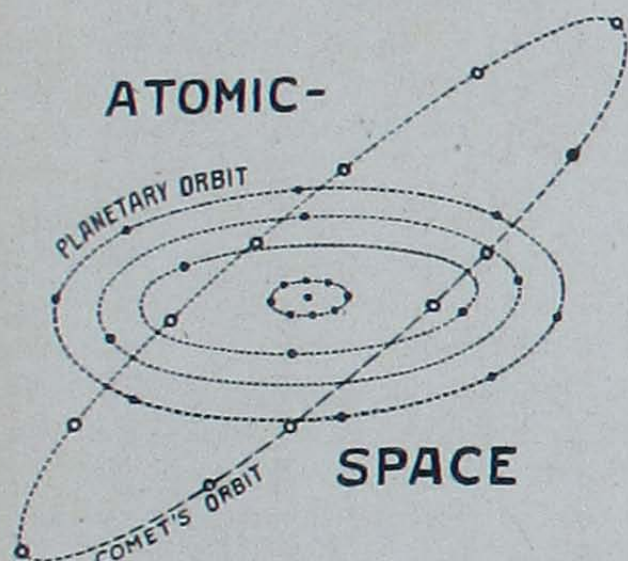


Fig. 24. Imaginary view of an atom according to modern interpretation. In the centre a nucleus of unknown nature. Electrons revolve all around it in ellipses.

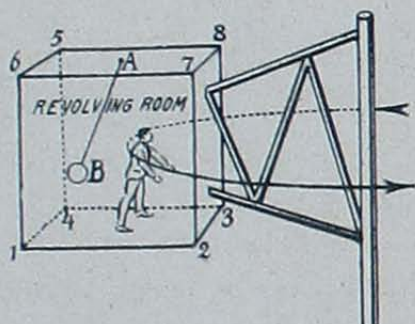


Fig. 25. A space attached to a vertical axis. It turns with a uniform velocity around this axis.

our bodies to a thousand millionth part, so that we can enter into a piece of matter (Fig. 23). We see innumerable formations of different shape, all in full motion. They exceed our own size a hundredfold and are nothing but the molecules, formerly invisible to us. Let us study their structure. On entering a molecule — it may be one of Malta — we cannot help being struck by the fact that the molecular space, the space to which the action or effect of the molecule is confined, is essentially empty. It contains three kinds of atoms, carbon, calcium and oxygen. They appear to us similar to the molecules as long as we saw them from the outside: as round bodies. All these atoms also are in quick motion. Yet as we said before, the most impressive point is this, that the molecules themselves are not a compact reality, but a

sort of illusion: empty space in which minute atoms are moving. We now, along with our instruments, reduce our size still further, until we can enter into the interior of an atom (Fig. 24). Again instead of a spherical solid mass we see an essentially empty space. In it very small bodies — perhaps smaller than ourselves — are revolving, and the whole manifestation of the atom, all the effect it produces, its characteristic qualities come about only by the motion of these planet-like particles, which swing around a minute centre in endless circles and ellipses. Again we see crude matter, on closer inspection, dissolve into the effect (the manifestation) of small moving particles. Now the reader must perceive how the real essence of matter eludes more and more the searching eye of man. And out of this truth he will understand the deep significance of this, seventh, proposition of the theory of relativity.

VII. Force and matter are identical (form a unit). Matter of bodies is only the effect, the manifestation, of the inherent energy.

This thesis anticipates the ultimate knowledge which we should reach by a further investigation of the minute structure of matter. Again we add that the theory of relativity and the deductions therefrom form a sort of completion, a perfecting, of those concepts which germinated during the classical period of development of natural philosophy.

That the deductions of the theory of relativity fitted so well into the simultaneous progress of our knowledge of the real nature or essence of matter, has contributed largely to its speedy acceptance by physicists. And the conclusions we are downright enticed into by the new doctrine satisfy the truly human longing for one-ness (or unity) of principle in the interpretation of nature. And though we have not yet arrived at the last deductions, we may already guess what the morrow will bring. We shall most probably return to the older view, that light is matter, matter in the sense of our new definition (thesis VII). And when we say: light is matter in its finest possible distribution, we do not say anything but: light is energy in smallest possible quantities. The last and finest particles of matter, which can possibly occur in the world, are those fundamental forms of reality, those wandering nodules of energy, which, on account of the minuteness of their inherent force, appear without mass and which yet yield a perceptible effect of energy. Thus the idea of an ether in a

new sense and form becomes again possible. This new ether is not the carrier of light and other phenomena, but it is light itself.

The reader will see here, how new possibilities of unexpected extent again present themselves to further research. Once the relativistic mode of looking at the universe has cleared; once the relativistic thoughts have penetrated into wider circles and have come to be further developed in thousands of thinking brains, a new epoch of enthusiastic creation will commence, a new time of flourishing prosperity of physical research. For the period of criticism and doubt is only a state of transition in the gradual growth of progressive thought. And though nature may recede step by step before the inquisitive efforts of science, though she may never reveal her last secrets, the fast and toil of exploration of ever new realms, together with the work of consolidation and organisation of new territories already conquered, will represent the purest satisfaction possible to the aspiring soul.

Additional Notes Concerning Einstein's General Principle of Relativity.

We must not conclude this "Introduction to Einstein" without devoting a few words to the improvements and amplification which the edifice of the special theory of relativity has experienced since its erection in 1905 and which were mentioned before as the "general theory of relativity".

We are on board a large ocean liner which proceeds at a uniform speed. To beguile the time, we make some simple pendulum experiments. We suspend an iron ball on a thread and let it swing. With a time-piece we measure the duration of an oscillation, perhaps by counting one hundred of them and noting down the time required. Then we make the pendulum four times as long as before and find that the duration of an oscillation has doubled. In such a way a variety of attractive laws are derived. Suddenly this doubt arises: Are these laws of the motion of a pendulum really true? Surely the ship has moved all the time, and has this motion no influence on the oscillations of the pendulum? Is it a matter of indifference, whether I observe the motion of a pendulum at rest on the surface of the earth or of one taking part in the motion of the steamer? The answer is given by the classical

principle of relativity: a uniform motion in a straight line has no influence on physical phenomena. Within such a uniformly moving system (on board the steamer for instance), the events of nature take exactly the same course as within a stationary system. Did we not see that this interchangeability of the two systems goes so far, that we are quite unable to make sure, which of the two systems is the resting, and which the moving one. We have to look somewhat closer into this and, at the same time, make good some sins of omission in our preceding discussion. We should have put more stress on the necessity of the motion of the observer in Fig. 15 being uniform, as this condition becomes now of special importance. If we carry out physical experiments on board a uniformly moving vessel or a uniformly moving railway train, or in any other similarly moving system, we obtain everywhere the same insight into nature's laws. The classical principle of relativity, therefore, takes this form now:

VIII. In all systems which move uniformly with reference to each other, nature presents the same aspect to us. The same laws ensue for the phenomena, if they are investigated in any one of these systems.

Out of all the innumerable possible objects of research we choose the determination of inertia. If I, still on board a uniformly moving ship, push a body forward, it will behave in exactly the same way as on the "resting" surface of the earth. It will move on in a straight line as long as the friction against its support permits. This is, as we know, the reason why we can play at billiards or fives on board a vessel, and why we ourselves can dance on deck. Conversely, we can draw from the behaviour of a body with regard to its inertia a conclusion as to the kind of motion. If a train enters the station, the brakes are put on, and its speed diminishes, its motion ceases to be uniform. All bodies on board that train become at once aware of this, as they receive an impetus forward. A suspended plum-line swings forward. We perceive that we "really" move relatively to the surface of the earth. Hence we may say: the fact of an acceleration indicates the existence of a real motion. For if it strikes us that an outside observer by the side of the embankment does not take part in our forward movement, we are not free to say: we move relatively to each other. For he will point out his enjoyable rest and our uncomfortable falling forward and will say: It is really I who am at rest, while you are really moving. So it would appear

as if we could recognise real motion simply by the existence of acceleration. The latter possesses such a variety of easily perceptible characteristics that there is no difficulty in recognising it.

This seems to be specially so in the case of a rotary motion. A globe or sphere set rotating will undoubtedly flatten at its poles. Thus a rotation can be established with unfailing certainty. If I, therefore, am in doubt whether it is the earth or the sky which rotates, I need only measure the dimensions of the earth. I find that it bulges out along the equator and conclude that it is the earth which really rotates.

Now let us imagine a sphere absolutely alone in all the universe! Some spirit may impart rotation to it. According to our preceding deductions, it must get compressed at the poles. The spirit will perceive this and will ask with us: why does this happen? We know no reason for it. For is not the statement: "the solitary sphere rotates" just of the same value as this: "it is at rest"? For how should we prove its rotation? Since for a body absolutely alone in the world all motions must be fulfilled. It is just as much at rest as in any kind of motion we chose. Since its real motion — if we want to talk of such a thing — could only be proved by referring it to some other, *fixed*, body. And this fixed body — just as well as any other body — is supposed not to exist. This means that the location and the kind of motion of a solitary body in the universe are both alike quite undetermined and indeterminable.

Further, our expectation, that the rotating solitary sphere should flatten at its poles, rests on the assumption, that it would show the phenomenon of inertia, since the centrifugal force is an effect of inertia. If we rotate a sphere sufficiently quickly, it will eventually tear asunder, and the pieces will either fly off in the direction of the tangent or unite in a ring poising over the equatorial region. These events appear — as Kant rightly saw — as an interaction between gravity and inertia. But while we possess a certain formal understanding for gravity which reaches, as it were, out of a body a spirit hand to grip and act on another. Though we are, of course, altogether ignorant of how gravitation really comes about — every datum necessary for the understanding of inertia fails us. We may admit that the parts of a solitary body attract each other so that it assumes the shape of a sphere; but if the experimenting spirit gives it an impetus,

we cannot help concluding that it must move uniformly in a straight line. But we have already seen that after our abandoning the notion of absolute space, a fixed, definite motion ceases to be possible.

Ernest Mach realised this difficulty. He suggested the only thinkable way out of it: inertia must be the result of the interaction of the whole material world on the body under consideration. That means to say: a body absolutely alone in the universe cannot be subject to inertia. (One might, of course, say: such a solitary body does not exist; but would not the whole of the world-mass — if it be finite — constitute such a body?) Inertia can be defined as a relation between the one body we have under observation and the entirety of the remaining matter in the world. Such a relation could only be hept up by gravity, which is known to us to act at a distance and as causing bodies to move. We cannot think of an immediate connection between gravity and light for this reason, because dark bodies also show the quality of gravitation. Though it must be the aim of modern science to reduce all action through empty space ultimately to processes partaking of the nature of light, yet so far we do not see how this can be done. But it is already possible to understand the identity of the effects of inertia and gravitation.

Let us imagine a space attached to a vertical axis (Fig. 25) and rotating around it at a uniform speed. If beings live in this rotating space, to whom this space is their world, we could explain the centrifugal force which the rotation sets up in this simple manner. A plumline suspended in A is attracted by the floor 1 2 3 4 and by the side-wall 4 5 6 1. If the string AB is cut, the body B will fall in a curved line (relatively to the observer in the rotating space) towards these two walls. But if the pendulum AB is set oscillating, it shows peculiar rotary movements, unknown to us ordinary terrestrial dwellers. It is true, the familiar Foucault-pendulum shows a similar rotation of the plane of its oscillations, but this phenomenon we can understand, as we can fortunately refer the earth's motion to the stars around us. If now the rotating space-dwellers are unable to look out of their six confining walls (just as, after all, we cannot look out of our world!), they will discover a variety of relations and connections which represent the natural philosophy of these rotary beings, a philosophy which cannot but turn out very different from our physics. These beings will have laws of motion which will be very unlike our own.

And now I must add boldly: Are we able to know and find out, whether we ourselves are not in the same position as these rotating-space-dwellers? What would this mean? In that case, perhaps, some other natural philosophy would be the real physics; not our own.

It must have been this thought which haunted — perhaps as a challenge — Einstein's brain. For his question, which led to the general principle of relativity, put this over-bold demand: "Surely it must be possible to give a description of nature's phenomena which is altogether independent of the location in space, of the dwelling-space or dwelling-world, of the observing beings." Cannot — after the proved pattern of the special theory of relativity — the conceptions of space, time and matter be modified and fitted together in such a way, that the principles, thus amended, suffice to lead to the same natural laws in regard to all dwelling worlds of observers, whatever their motion.

The mathematical investigation involved was so difficult, that nobody would have been able to carry it out, if it had not already been done. Two men, endowed with the highest genius for mathematics, Gauss and Riemann, had done this work. Not one among our living mathematicians could compare with them. These two giants had evolved a secluded theory in which all lay ready for Einstein's investigation. But even then and in spite of the work of his predecessors, the treatment of the problem was too difficult for the deep thinker Einstein. He had to look about for assistance and obtained it from M. Marcel Grossmann. With his help the daring question was answered in 1916. It was proved to be possible, thus to modify the conceptions of space, time and matter, and to combine them in such manner, that a picture of the world ensued, which is free from all individual singularities appertaining to the observer himself.

The general theory of relativity has led to those renowned results which attracted such wide-spread attention in the educated world; viz. The deviation of light rays under the influence of gravity and the change in the orbit of Mercury. Nobody who examines these results can doubt that we have here a magnificent performance of research before us. And he who is acquainted with the history of physics, will agree with the opinion expressed by an eminent Englishman (J. J. Thomson in Cambridge) when he said: "Einstein's doctrine is the most important advance in physics since Newton."

